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CLIMATOLOGY, HYDROLOGY, AND HYDROGRAPHY OF THE VERMILLION BASIN

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CLIMATOLOGY, HYDROLOGY, AND HYDROGRAPHY OF THE VERMILION BASIN

- Vermilion Basin: Synoptic Weather Types and Environmental Responses
  C. L. Wax, R. A. Muller, M. J. Borengasser

- Vermilion Basin: Hydrologic and Hydrographic Processes
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NOTICE

Part I • Vermilion Basin: Synoptic Weather Types and Environmental Responses

by C. L. Wax, R. A. Muller, and
M. J. Borengasser

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ACKNOWLEDGMENTS

Efforts toward implementation of coastal zone management in Louisiana have enlisted the interest and participation of many public agencies and institutions. As a cornerstone for this program, scientific information from every available source is being compiled and digested in a series of Coastal Zone Management reports. The collection is ultimately intended as an authoritative central reference source of persons involved in administration of an operational CZM program.

The information presented in this report has been synthesized from research studies administered by the Louisiana Sea Grant Program, a part of the National Sea Grant Program maintained by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce.

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INTRODUCTION

The coastal waters of the Vermilion Basin respond quickly to the winds and weather on opposite sides of warm and cold fronts across southern Louisiana and the northern Gulf of Mexico. This report characterizes the synoptic weather types of the basin. In combination with a water-budget analysis of the basin, the synoptic weather types are especially useful for study of relationships between weather and regional environmental responses such as estuarine water levels. The synoptic weather types also index related environmental inputs like solar radiation. In this report, therefore, the synoptic weather types are used as an all-encompassing index of climatic inputs to environmental responses within the Vermilion Basin.

With the exception of daily temperature and precipitation data taken at several cooperative stations of the National Weather Service, few routine climatic data are observed in the basin. The cooperative station data and measured streamflow of the Vermilion River and Bayou Teche have been used for the water-budget analysis of the basin. Muller (1977) has established a synoptic climatic calendar from first-order weather station observations by the National Weather Service at Moisant Airport, New Orleans, for application as an environmental baseline inventory. Muller and Wax (1977) have extended the synoptic baseline analysis to the observational data of the National Weather Service at Lake Charles, and they have shown that the weather types have similar properties at both locations. Because of the similar climatic properties by weather types along coastal Louisiana, we have prepared a synoptic climatic calendar for the Vermilion Basin by interpolation between the New Orleans and Lake Charles synoptic calendars; the synoptic calendar provides the basis for the analysis of water level responses in the Vermilion Basin.

The Vermilion Basin is located along the central Louisiana coast, about midway between New Orleans and Lake Charles. The Vermilion River is the primary drainage system of the basin, which is separated from the Mermentau Basin to the west by a system of locks on canals crossing the drainage divide. On the east, the basin extends to the western levees of the Atchafalaya Basin Floodway. The Vermilion Basin includes the waters of Bayou Teche. The drainage area of the basin is somewhat smaller than most of the other drainage basins of coastal Louisiana.

Elevations throughout the drainage basin are low, but substantial areas of the basin are relatively well-drained Pleistocene terraces. The floodplain of the Vermilion River is well defined on the Pleistocene terrace, and the river discharge is confined to the channel until it flows into Vermilion Bay. The coastal wetlands include salt, brackish, intermediate, and fresh marshes. Vermilion River water mixes with salt water in Vermilion Bay and is sometimes then swept over the coastal marshes as brackish or saline water. Extensive forests are limited primarily to the floodplain of the Vermilion River.

Land uses in the Vermilion Basin are surprisingly intensive, and they have considerable environmental impact. The Pleistocene terraces are extensively used for the production of rice, sugarcane, soybeans, and pasture. Rice is irrigated from both the Vermilion River and ground-water sources. There are extensive wildlife refuge areas in the wetlands near the coast, and these uses are not always compatible. A line of salt domes is a remarkable feature of the landscape, and the density and intensity of oil and natural gas production is very high.

The Vermilion Basin is part of a broad region of the Southeastern United States with humid subtropical climates. The basin is dominated by warm, moist maritime tropical air from the adjacent Gulf of Mexico. The maritime tropical air is displaced frequently during winter and spring by outbreaks of continental polar air from Canada which usually persist no longer than 3 or 4 days. These outbreaks of continental polar air occur less frequently during autumn and only rarely during summer.

Usually there is a sharp contrast of weather conditions and events on either side of the frontal boundary separating polar and tropical air. Following passage of a cold front during winter, the sky is typically covered by low clouds driven by strong, gusty, northerly winds, temperatures fall into the 40s, and intermittent drizzle adds to physical discomfort. Usually within 24 hours the sky clears and the winds abate. Balmy conditions reign in the tropical air to the south of the cold front; in January air temperatures reach the upper 60s and low 70s, and billowy cumulus clouds are swept along by gusty southeasterly winds.

Precipitation is usually associated with the passage of warm and cold fronts, and heavy intensity showers, usually lasting no more than an hour or two, occur within squall lines ahead of cold fronts during winter and spring. General rains of 12 to 24 hours duration are uncommon. During summer, precipitation usually occurs as brief, heavy, showers and thunderstorms between late morning and early evening, with each shower covering a very small area. Average annual precipitation over the basin ranges between 55 and 60 inches. Although average rainfall is far greater than the normal climatic requirements for evaporation and transpiration, rainfall variability results in occasional local flooding upstream and fresh water outflow in Vermilion Bay. Extended dry periods can also be damaging to unirrigated crops on Pleistocene terraces.

SYNOPTIC WEATHER TYPES

The following introduction to the synoptic weather type system, taken from the Barataria Basin report (Borengasser, Muller, and Wax 1976), is included here to provide essential background to the weather-type properties and their environmental inputs. Certain other sections of this report closely parallel the Barataria Basin report and are identical excepting the different data base used in the climatic analysis. This was done intentionally to provide maximum continuity between the two reports and to reiterate the concepts developed in the earlier report. Physical parameters (air temperature, relative humidity, wind, etc.) derived from meteorological observations make up what is generally thought of as weather, and, in the longer term, climate. Since weather events exert such a strong influence over environmental processes and responses, an understanding of frequencies and extremes of weather properties in a region can provide valuable insight into the functions of that region as a natural system. Analysis of these weather properties and consequent environmental interactions forms the basis of climatological interpretation.

Conventional climatological analysis often relies on statistical generations of means, extremes, and frequencies of meteorological data for long time periods. It is now recognized that these elementary climatic data are inadequate in much bioclimatological work (Barry and Perry 1973, p. 427); year-to-year variation of global circulation regimes precludes precise specification of a region's climate and environmental interactions in these terms.

Climatic data need to be organized so their variations can be related directly to variations in selected environmental parameters, thereby providing a means of assessing climate's contribution in causing a natural system to function. For this purpose it is useful to group climatic data into synoptic classes rather than treating the whole frequency distribution together. Organizing regional climate into a synoptic framework combines selected parameters into weather types and characterizes selected weather properties associated with each type.

The daily weather can be organized on the basis of atmospheric circulation into relatively few types, which provide an environmental baseline inventory. This synoptic approach is from a local perspective, and the subcontinental atmospheric circulations are categorized in terms of weather.

From the perspective of Lake Charles, a first order weather station of the National Weather Service, the synoptic weather situation at 0600 hours CST on the daily weather map of the National Weather Service has been classified into one of the eight all-inclusive types established by Muller (1977) for each day from 1971 through 1974. Brief comments about each synoptic type (Figure 1) follow:

Pacific High (PH): The circulation usually brings mild and relatively dry air following a cold front across southern Louisiana. Most often the center of the surface high is over the eastern Pacific Ocean or west of the Rocky Mountains.

Continental High (CH): The center of the anticyclone is usually east of the Rocky Mountains, and the associated surface air flow is from Canadian or Arctic regions. This weather type is restricted to fair weather associated with the core of the anticyclone.

Frontal Overrunning (FOR): This synoptic type occurs frequently when the polar front is more or less stationary along the Gulf Coast or over the northern Gulf. Frequently waves develop along the front over the western Gulf, and then sweep northeastward bringing heavy clouds and precipitation to southern Louisiana. Generally either polar or Arctic air is associated with this weather type.

Coastal Return (CR): When the crest of an anticyclonic ridge drifts to the east of Louisiana, surface winds over Lake Charles veer from northeast to east to southeast. During winter and spring the surface air usually represents continental polar air modified by short passages over the Atlantic and Gulf during clockwise circulation near the Gulf Coast. During summer and autumn, in contrast, this type also includes the Bermuda High situation, when a ridge of tropical air extends westward from the Atlantic over the Southeastern States, and the air flow over Lake Charles is again from easterly components.

Gulf Return (GR): When the anticyclonic ridge drifts further eastward, the isobar configuration usually results in a strong return flow of maritime tropical air from the Caribbean and Gulf on the western margin of the ridge. A similar flow occurs when developing low pressure over the Texas panhandle begins to sweep northeastward. In both of these situations, the coastal return flow of modified continental air is gradually replaced by moist tropical air as surface winds continue to veer from the east to southeast to south.

Frontal Gulf Return (FGR): When the return flow is affected by convergence or lifting along an approaching front, the resultant weather deserves special designation as a separate weather type. Arbitrarily, this type includes periods when a cold front from the west or north is located within a zone extending out about 300 miles from Lake Charles. This type also includes periods after a northeastward-moving warm front has crossed over Lake Charles, but only until the front has progressed about 100 miles to the northeast. Hence, FGR is restricted to warm-sector periods when fronts are affecting the weather over Lake Charles, and GR includes the same air flow with distant fronts.

Gulf Tropical Disturbances (GTD): During summer and fall, southern Louisiana is occasionally influenced by tropical systems which usually drift from east to west across the northern Gulf. These disturbances range from relatively weak easterly waves to rare but severe hurricanes such as Camille in 1969. The tropical disturbances are associated with instability through deep moist layers, and copius precipitation is often produced.

Gulf High (GH): Especially during summer there are periods when the western extension of the Bermuda High is displaced southward over the Gulf of Mexico, and the weak local circulation is from the southwest. This flow consists usually of maritime tropical air, but occasionally somewhat drier continental tropical air from western Texas will reach Lake Charles. Very occasionally during winter and spring a flat high pressure cell over the Gulf will also draw warm, dry air from Texas or Mexico over Louisiana.

Cataloging the weather into types involves the formulation of synoptic weather type calendars based on occurrence and duration of each weather type. The procedure involves studying daily surface weather maps and classifying the weather at Lake Charles into one of the eight types. Each month is then structured into a calendar by fitting the observational data, published for every third hour, to the weather map analysis of synoptic types.

SYNOPTIC WEATHER TYPE PROPERTIES

The calendars and monthly summaries of meteorological properties by synoptic weather types provide a climatic baseline from which inferences about environmental interactions may be drawn. Table 1 summarizes the properties of weather types for four Januaries (1971-1974) and illustrates the contrasts among weather types. At 0600 hours in January, for example, Table 1 shows the orderly sequence of mean temperature in degrees F running from CH as the coldest to GR and FGR as the warmest. Both the dewpoint temperature and relative humidity follow a relatively similar progression. There is also a logical progression of mean wind directions given in azimuths from 01 through 36 to represent 10° through 360°. Mean wind speeds are in knots, and the stronger winds associated with frontal activity are obvious in the table. Cloud cover is relatively high, except for the CH type.

Precipitation and evaporation are closely related to the weather types. Table 2 shows which weather types produce precipitation. It is important to note that 31 percent and 32 percent of the total precipitation during the four-year period was associated with the FGR and FOR types respectively: hence frontal activity accounted for almost two-thirds of the rainfall. These two weather types were present only 27 percent of the time.

Reference to Table 2 illustrates that rates of evaporation change with each weather type. When it is cloudy and the air is moist (as in FGR), evaporation will be much less than when it is clear and the air is drier (as in CH). Solar energy input and vapor pressure gradient are conducive to evaporation in the latter case.

Solar radiation received at the earth's surface (insolation) is related to the synoptic weather types. Table 3 summarizes the daily insolation data organized by weather types at Lake Charles for the period 1963-73. Median values were chosen to represent a "typical" day in a month (Figure 2) since median values tended to follow the clustering of data points more so than the mean values. The median is also less affected by extreme values. This may be caused by errors in data measurement, data tabulation, or weather typing. For example, Table 3 and Figure 2 reveal that certain of the weather types display similar patterns of insolation throughout the year. CH, GH, and PH have the highest insolation values, while FOR and FGR have the lowest values and GR and CR have intermediate values. GTD is highly variable but has generally moderate to low insolation. GR also very closely approximates the mean ($\bar{x}$) of all insolation values. Insolation patterns for each weather type are inversely related to the amount of cloud cover (Tables 1, 5, 6 and 7), as would be expected. However, insolation is not solely a function of cloud amount but also of cloud type, fog, relative humidity, and dust. Each weather type contains an associated range of values for these properties.

Just as cloud cover and other weather properties vary within each weather type, insolation also shows considerable variation about either mean or median. CH, GH, and PH, again, have a common characteristic of low degree of scattering of daily insolation values (Figure 3). This is probably due to the consistently low cloud cover with each of the three weather types. The remaining weather types display a higher degree of scattering (Figure 4). In the summer, insolation values for each of the weather types are both more widely scattered and more similar to each other.

WATER SURPLUS CALCULATIONS

Rainfall, which can be measured directly (if not accurately), is not the best indicator of environmental stress within a natural system. The difference in incoming precipitation and potential evapotranspiration (energy demand on the environment for water) is a much better index. A water-budget framework in conjunction with the synoptic weather types provides useful estimates of moisture transport and exchange and of water surplus generation within a basin.

Freshwater input into a basin can be estimated by use of a daily climatic water budget developed by Thornthwaite (1948). Figure 5 can be used to discuss the basic water budget components summed on a monthly basis as they apply to Baton Rouge for the period 1960 through 1967 (Muller and Larimore 1975). Potential evapotranspiration (PE) is represented by the upper continuous curve. Potential evapotranspiration may be defined as the maximum amount of evapotranspiration that would take place with a continuous vegetation cover and no shortage of soil moisture to the vegetation over a large area. Potential evapotranspiration is based on energy supplied principally by solar radiation. Thornthwaite based his estimates of PE upon mean monthly temperatures and day-length factors. In a daily water budget, mean daily temperatures are utilized instead.

The horizontally ruled areas in Figure 5 represent actual evapotranspiration (AE). Since declining soil moisture inhibits actual evapotranspiration, AE is often less than PE. This is especially true in the summer and autumn in Baton Rouge. When AE is less than PE, a deficit (D) occurs and plants begin to suffer from the decreased soil moisture and lower transpiration rates.

Of more immediate concern in this study is the surplus (S). Surplus is the "excess precipitation" after accounting for losses to evapotranspiration and soil-moisture storage. Surplus is moisture available for streamflow or groundwater recharge. Figure 5 illustrates that surpluses are greatest in winter and early spring when precipitation is high and PE is low.

Figure 6 illustrates how surplus is calculated for vegetated surfaces. Precipitation (P) that falls on the vegetative surface is subjected to PE. If P-PE is negative or zero, all of the precipitation is evaporated and no moisture is left for surplus. If P-PE is positive, some moisture infiltrates into the soil and the remaining moisture becomes surplus (groundwater recharge or streamflow). The amount of positive P-PE entering the soil can be no greater than soil moisture storage deficiency prior to precipitation.

A computer program of the Thornthwaite daily climatic water budget prepared by Yoshioka (1971) was modified for application to Louisiana coastal wetlands (Borengasser 1977). The four primary modifications were: (1) potential evapotranspiration, (2) soil moisture storage, (3) precipitation intensity, and (4) marsh and open-water surplus. Indirect evidence from streamflow data and evaporation pans suggests that the Thornthwaite PE estimates for Louisiana are a little low in winter and a little high in summer, with overall annual estimates probably less than 10 percent below "real-world" PE (Muller and Larimore 1975). As a result, 12 monthly coefficients were inserted to convert Thornthwaite PE to approximate adjusted pan evaporation.

A two-layer soil moisture storage replaced a single-layer storage in the original Thornthwaite model. This, together with a precipitation intensity factor, allows for moisture exchanges to operate easily within the upper soil moisture zone and for a more gradual exchange to occur with depth.

Open-water and marsh areas were treated differently from well-drained vegetated areas (Muller 1977). Since water is nearly always near the surface in the marsh and always at the surface in the open-water areas, no soil moisture storage factor was used. Surplus (S) then becomes the positive P-PE term (Fig. 7; see Fig. 6 for comparison with well-drained areas).

Water surplus for Vermilion Basin is computed as follows:

1) land surface: $S_L = (P_L - PE_L) - \Delta ST_L$, where S_L is the surplus over a well-drained, vegetated surface (land); P_L is the precipitation over land; PE is the potential evapotranspiration over land; $(P_L - PE_L)$ is positive; and ΔST_L is the change in soil moisture storage.

2) open water surface: $Sw = Pw - PEw$, where Sw is the surplus over open-water or marsh areas; Pw is the precipitation over open-water; PEw is the potential evapotranspiration over open-water; and $(Pw - PEw)$ is positive.

3) basin surplus: $S = C_L S_L + CwSw$, where S is the basin surplus, and C_L and Cw are fractions of the basin area occupied by land and open water, respectively.

Table 4 illustrates the weighting techniques that were applied to the climatic stations and the different land (or water) surfaces in Vermilion Basin (Figure 8). Column 2 lists the coefficients given each station during the analysis while columns 3 and 4 show those given to surfaces based upon percentage of marsh. Table 4 does not include measured discharge for Bayou Teche at Arnaudville, which was added to the ungaged surplus. The addition of Bayou Teche drainage above Arnaudville adds 1531 square miles, for a total basin area of 3613.9 square miles.

CHARACTERIZATION OF 1971-1974

Averages of synoptic weather type properties at Lake Charles for the years 1971-1974 characterize the climate of Vermilion Basin. Table 5 shows the percent of time each weather type occurred. Weather conditions associated with each type were present the actual amount of time shown in the table. For instance, CH type was present 22 percent of the time, GR 20 percent, and GTD only 3 percent. The continental polar (cP) index is an indicator of the occurrence of drier, cooler continental air over the basin (38 percent of the time), whereas the tropical (mT) index indicates the amount of time moist, warm air was present (43 percent of the time). More important than the annual totals, though, are the percent of time the synoptic weather types were present in each month and their seasonal progression of occurrence. Storminess, as indicated by the storminess index, diminishes in the summer, pointing out the seasonal retreat of frontal activity from the region.

Mean properties of each weather type have been formulated for January, April, July, and October, providing an assessment of the impact of weather through the year when related to occurrence and duration of each synoptic weather type (Tables 1, 6, 7, 8). Annual regimes of mean weather type properties for CH and GR (the most dominant weather types in terms of duration) are shown in Tables 9 and 10. The 0600 CST means represent minimum values, whereas 1500 CST means represent maximum values for each of the parameters.

Table 11 shows the percent of time precipitation occurred within each weather type, given in terms of percent rainy hours (defined as any hour during which at least 0.01" of precipitation was recorded). Precipitation measured during the 4-years is summed by synoptic weather types in Table 2. The direct relation of synoptic weather type occurrence to precipitation is easily seen by reference to Figure 9. Three weather types (FOR, FGR, GTD) account for 78 percent of the total precipitation, yet they were present only 30 percent of the hours in the 4 years. The intensity of rainfall associated with GTD is evident when it is considered that it occurred only 3 percent of the total hours, 18 percent of which were rainy hours, yet the weather type produced 15 percent of the precipitation.

ANALYSES OF RELATIONSHIPS BETWEEN BASIN CLIMATOLOGY AND ENVIRONMENTAL RESPONSES

Solar radiation is often thought of as the ultimate driving force for most environmental systems, either directly, as sunlight and photosynthesis, or indirectly, through the atmospheric circulation and associated weather. Some very important environmental parameters can also be treated as responses to meteorological inputs. Water levels in marshes and estuaries are affected by wind direction and speed, the fetch and duration of the wind, atmospheric pressure, rainfall and evapotranspiration, and, of course, astronomical tides. Wind direction tends to be especially significant because northerly winds drive Gulf waters away from the coast, lowering water levels across the coastal wetlands; and southerly winds drive Gulf waters up against the coastline, raising water levels across the wetlands. Salinity levels are similarly affected, especially by wind and precipitation-evaporation ratios.

Although rigorous relationships between wind speed and stress on water surfaces are known, the lack of standard meteorological data across the coastal wetland inhibits application of these relationships to environmental management objectives. There is also a need for more comprehensive relationships between weather and the normal day-to-day variation of environmental conditions over broad areas of the coastal wetland. The synoptic weather types can be utilized for this resource objective. Specifically, the sequences of weather through time, in terms of the synoptic weather type calendars for Lake Charles can be compared to water level changes in Vermilion Basin, in order to ascertain the degree of response between weather and environmental parameters. The synoptic weather types at Lake Charles represent an environmental baseline which supposedly forces water level changes in the basin.

Muller and Wax (In press) have established that characteristic weather associated with the weather types is essentially the same at both New Orleans and Lake Charles. This uniformity, on the average, establishes the credibility of extending these baseline data, with an appropriate time lag, to areas along the immediate coast where no climatic data are available.

The year 1971 was selected for a detailed analysis of the relationships between synoptic weather types and environmental responses in Vermilion Basin. This year includes much of the climatic variation which is characteristic of the Gulf Coast. The first half of the year was much colder and drier than normal, and the second half much warmer and wetter than normal. In addition, a nearly complete set of environmental response data was available.

To establish the relationships between meteorological forcing functions, surplus precipitation and water levels, all of the daily weather events and associated properties that occurred in the basin during 1971 have been placed into one of the eight weather types. Though other processes such as oceanographic forcing functions are recognized as important within the system, synoptic weather type organization allows for a more comprehensive evaluation of environmental responses.

There are several reasons for the association between synoptic weather types and environmental responses, such as water levels, being imperfect. One is the geographical distance between the location of the synoptic weather type calendar at Lake Charles and Vermilion Basin over 100 miles to the southeast. Stationary weather fronts often persist for several days over this region, with the Frontal Overrunning (FOR) or Continental High (CH) types to the north at Lake Charles, and the Frontal Gulf Return type (FGR) to the south along the coast. In this situation, water levels normally continue to increase in the basin, but the baseline data at Lake Charles indicate water-level decreases should be expected. During 1971, these stationary fronts did not persist over the basin, but a few adjustments to the synoptic baseline data had to be made several times over the entire year to be representative of Vermilion Basin conditions. These adjustments were based on synoptic weather maps.

The synoptic types are inclusive of all situations, so there are also a number of marginal or very weak situations when winds were weak or ineffective in changing water levels significantly. Similarly, wind directions in these marginal situations did not always remain consistent with the means shown in Table 12, which are characteristic of each weather type and which govern the responses of water levels to the weather types.

Water Level Analysis

The synoptic weather types have been grouped into combinations that are thought to produce similar responses of water levels over the Vermilion Basin. The table below lists the synoptic weather type combinations that are utilized in these analyses:

Combination 1	CR, GR, or FGR changing to FOR, PH, CH, or GH (cold front)
Combination 2	PH and GH
Combination 3	CH and FOR
Combination 4	GH, PH, CH, or FOR changing to CR
Combination 5	CR
Combination 6	GR and FGR
Combination 7	GH, PH, CH, FOR, or CR changing to GR or FGR (warm front)
Combination 8	GTD

Combination 1, representing a cold front passage, should be expected to decrease water levels, as should combinations 2 and 3 since they are associated with west to northeast winds (Table 12). Combination 4 is associated with winds shifting gradually from northwest to east or southeast, so water levels should increase. Combinations 5 and 6 tend to produce rising water levels since they are associated with winds from east through south-southwest. Combination 7 represents a sequence of weather type changes through the 24-hour period that can best be described as passage of a warm front over the basin; it should be understood that it is only necessary for one or more of the five synoptic weather types to occur before passage of the warm front. Water levels should tend to increase during combination 7. There are no preferred wind directions associated with combination 8 because tropical disturbances can approach the basin from all directions except northwest through northeast.

The analysis of relationships between the synoptic weather types and environmental response was performed by summing daily changes in water levels (0600-0600) that occurred during each of the weather type combinations. Water level data measured at Vermilion Lock and Luke's Landing were analyzed.

Water level data used in the analyses had tidal effects filtered out by use of a 41-point filter verified and modified by Ormsby (1961) leaving water level variations that resulted from only climatological forcing functions. Days having a 24-hour change in water level of less than 0.2 ft were omitted from the analyses. Days with surplus (excess precipitation) were separated from days with no surplus.

The relationships established at Vermilion Lock, using observations on 264 days, are displayed in Figure 10. For example, filtered water levels rose a total of 12.2 ft and fell a total of 2.1 ft over the year during days that were classified as combination 6 with no surplus. Hence the predicted responses were not observed in every case, but expected relationships are firmly established. For instance, combinations 1, 2, and 3 drove water levels down, and 4, 5, 6, 7, and 8 drove water levels up. Cold front passages (1) demonstrated no departures from the expected relationships. Ratios of increments up to increments down are shown in the figure.

Results for Luke's Landing are shown in Figure 11. The same strong relationships between weather types and water level response were observed in the analysis there, using 230 days.

The effect of surplus on the relationships is seen in both Figures 10 and 11. It was expected that decreases in water levels would be lessened by surplus precipitation and that water levels increasing as a result of the weather types would be augmented by surpluses.

At Luke's Landing this relationship is strongly established. For example, combination 2 causes increases in water levels on nonsurplus days 2 times greater than decreases, whereas on days with a surplus, increases are 3 times greater than decreases. Combination 8 causes water level increases 3 times greater than decreases on surplus days. The ratios for combination 7 and 13 to 1 increases on nonsurplus days and a perfect 1:1 relationship on surplus days.

At Vermilion Lock the relationships associated with surplus days are not as firm. Ratios for combination 3 are 1 to 1 decreases on nonsurplus days and 3 to 1 decreases on surplus days. Combination 6 shows 6 to 1 increases on nonsurplus days but only 2 to 1 increases on surplus days. It is reasonable to expect that surpluses would have a significant effect on water levels in constricted drainage areas but little or no effect on water levels in the lower basin adjacent to the Gulf.

Table 13 summarizes salient information about response characteristics found at the two locations. It should be emphasized that values in Table 13 represent responses averaged for all weather types collectively, separated into surplus (S) and nonsurplus (NS) situations. The mean responses in the table are therefore the averages of all observations in each of the surplus categories, and the range of responses given is the range between the largest negative and the largest positive response observed at each location regardless of weather type. The information was calculated using the entire spectrum of weather at each location and is consequently not related to the occurrence of separate weather types, but rather to location alone.

One inference from the information in the table pertains to the character of the mean responses. Since none of the mean responses in either of the surplus situations is zero, but instead are all either positive or negative, a greater influence of either those weather types that increase or those that decrease water levels is indicated at the two locations. The range of responses to both surplus and nonsurplus conditions demonstrates the variety of impacts weather can have in forcing water level changes.

CONCLUSIONS

In coastal Louisiana a full series of hourly meteorological observations are made only at the first-order stations of the National Weather Service at Moisant Airport, New Orleans, Municipal Airport at Lake Charles, and at Boothville in the lower delta of the Mississippi River. The Coast Guard also makes some very limited observations at several stations, but there are no other regular data series within the coastal zone from which to estimate natural regimes such as estuarine water levels. The synoptic weather types and their daily combinations at the first-order weather stations therefore represent useful climatic baselines which can be applied to describing and understanding environmental regimes across the entire coastal zone.

This analysis of relationships between climatic inputs and water level regimes in the Vermilion Basin estuaries illustrates how elements of the environment respond to variations in weather as indexed by the synoptic weather type calendars. For example, the analysis shows that water levels respond most sharply and most consistently to the changing of weather types, represented by passage of a cold front, the rearing of winds from northerly to easterly or southerly, and the passage of a warm front. Less well-defined relationships are found in connection with the weather types representative of sustained weather conditions - long periods of northerly winds or southerly winds - during which maximum responses or effects are rapidly reached, and further effects of weather on water-level responses diminish thereafter.

The study documents that cold front passages and northerly winds initially depress coastal water levels and that warm front passages and southerly winds initially cause rising water levels in the basin. Precipitation, particularly the surplus of the water budget analysis, also causes water levels to rise. However, the effects of surplus precipitation in the lower areas of the basin where surplus and runoff are not concentrated are small and not very significant.

The calendars of synoptic weather types produced for this analysis represent the normal day-to-day procession of weather events over the Vermilion Basin. The responses of natural elements of the estuarine environments, therefore, are related on a daily basis to the meteorological properties of the weather types such as wind. For example, a typical fall, winter, or spring sequence of weather over the basin includes northerly winds after a cold-front passage (combinations 1, 2, and 3), changing to easterly winds (combinations 4 and 5), then to southeasterly or southerly (combinations 6 and 7), and then back to northerly winds following another cold front. The established water-level responses are falling water levels (combinations 1, 2, and 3), rising water levels (combinations 4, 5, 6, and 7); followed again by falling water levels (combinations 1, 2, and 3). It is important to recognize that these water-level fluctuations are in addition to the regular tidal oscillations predicted for each day for an entire calendar year. A vigorous cold front passage can completely eliminate the normal-predicted tidal oscillation, so that, for example, low water occurs when a high tide is predicted. Similarly, sustained southerly winds usually result in high water and extensive wetland flooding. The water-level changes induced by sequences of synoptic weather types also contribute to the mixing and redistribution of nutrients for coastal fisheries. The day-by-day weather sequences need to be taken into account in any effective environmental management plan for the estuarine waters of the Vermilion Basin.

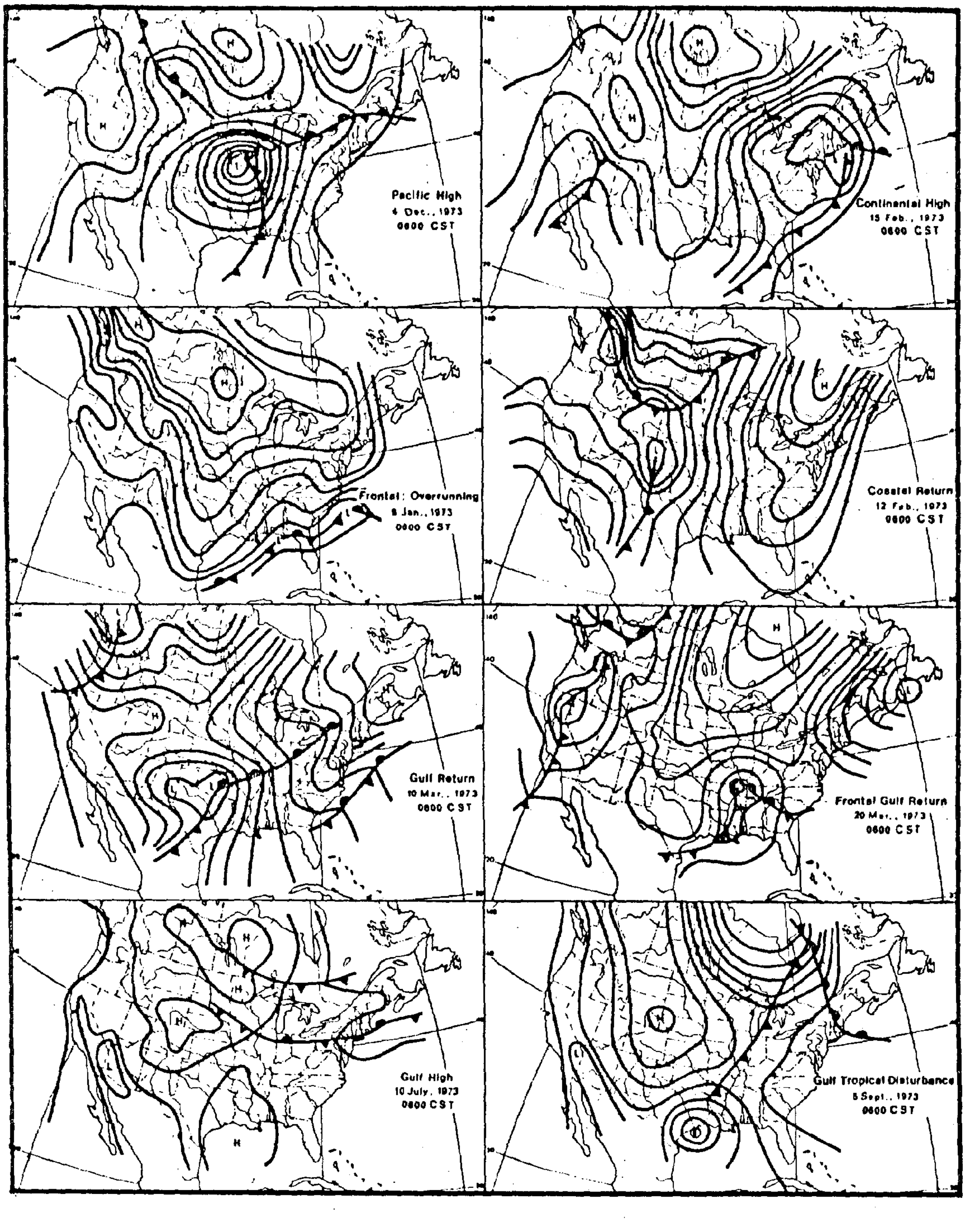


Fig. 1. Illustrations of synoptic weather types (modified from Muller 1977).

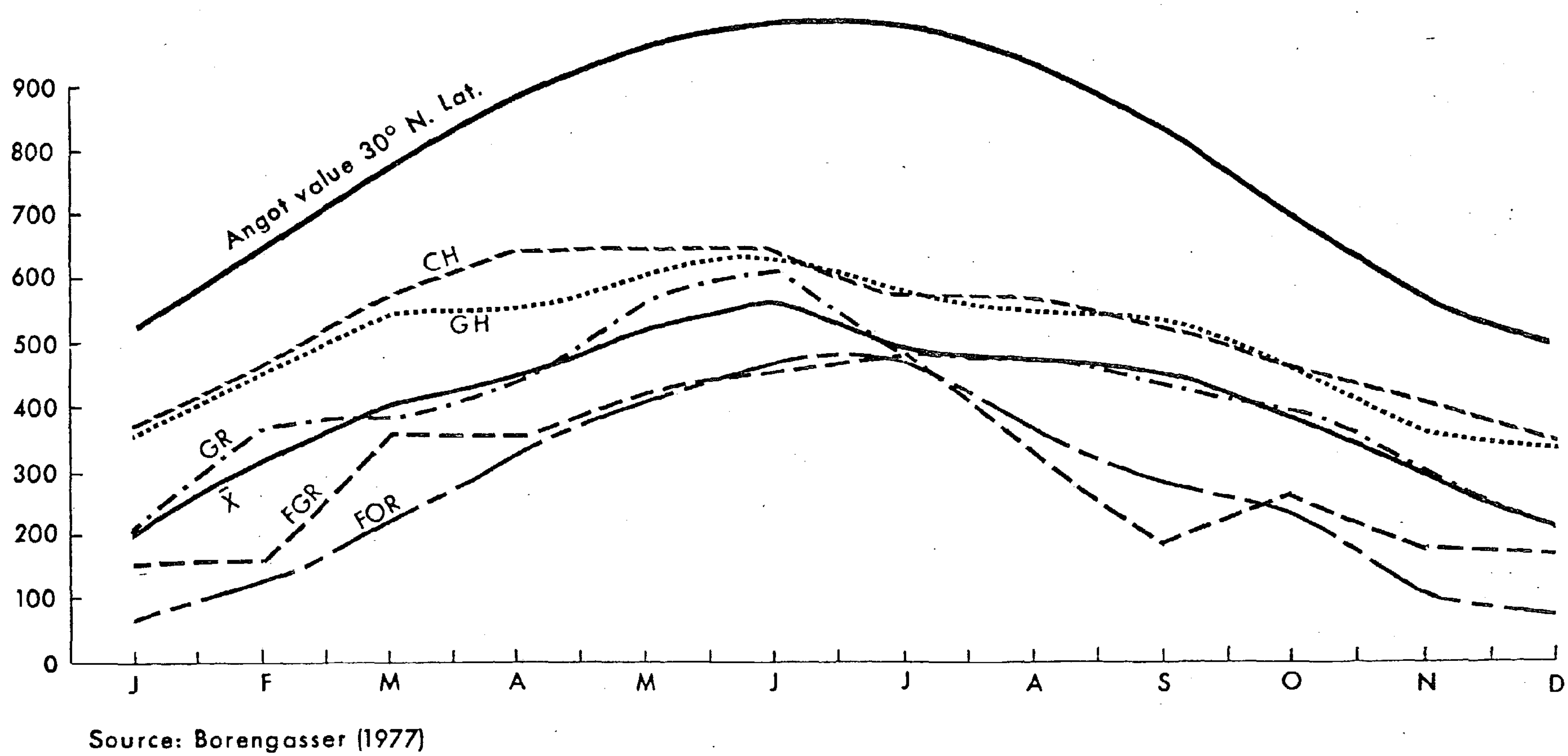
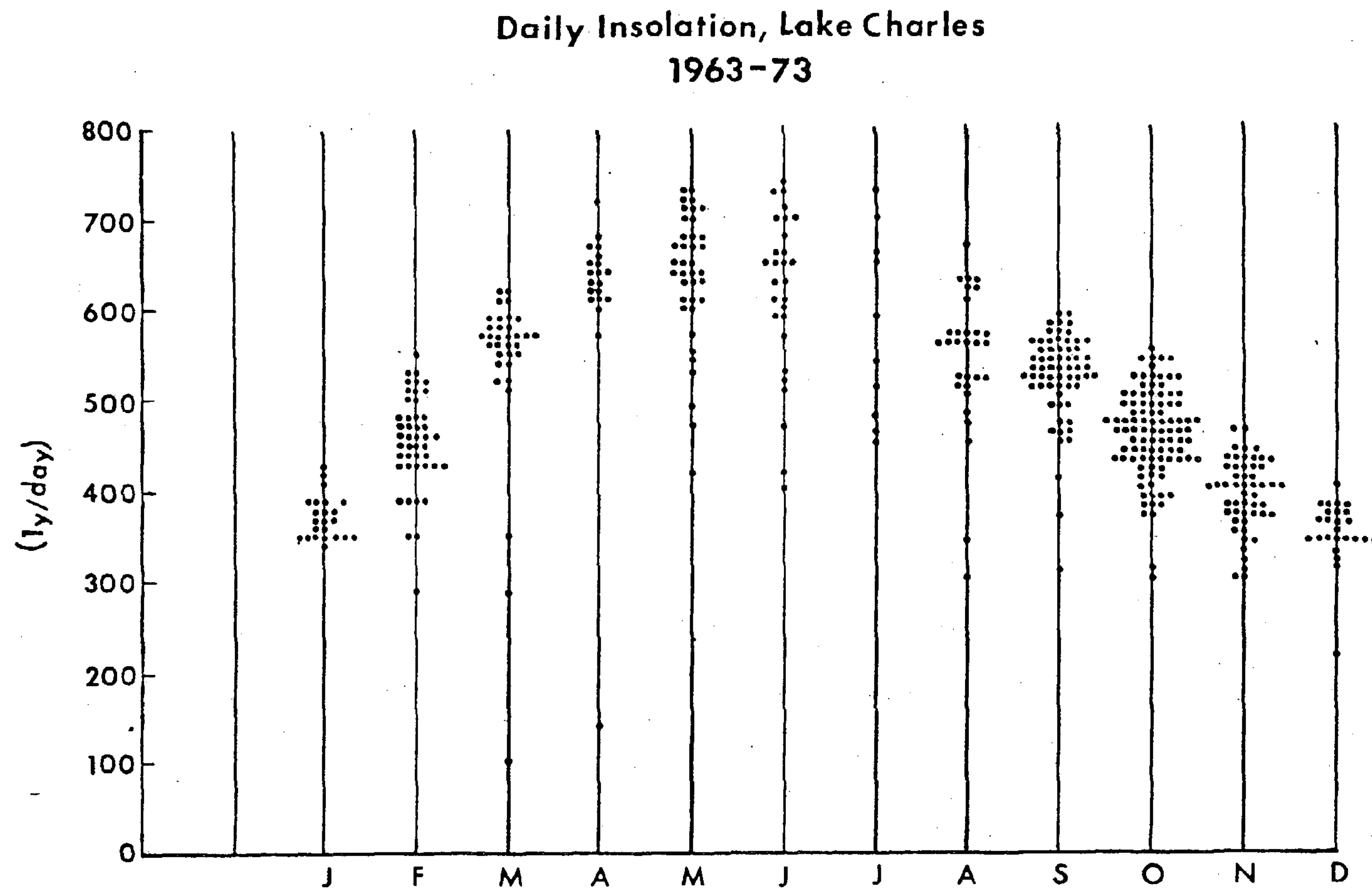
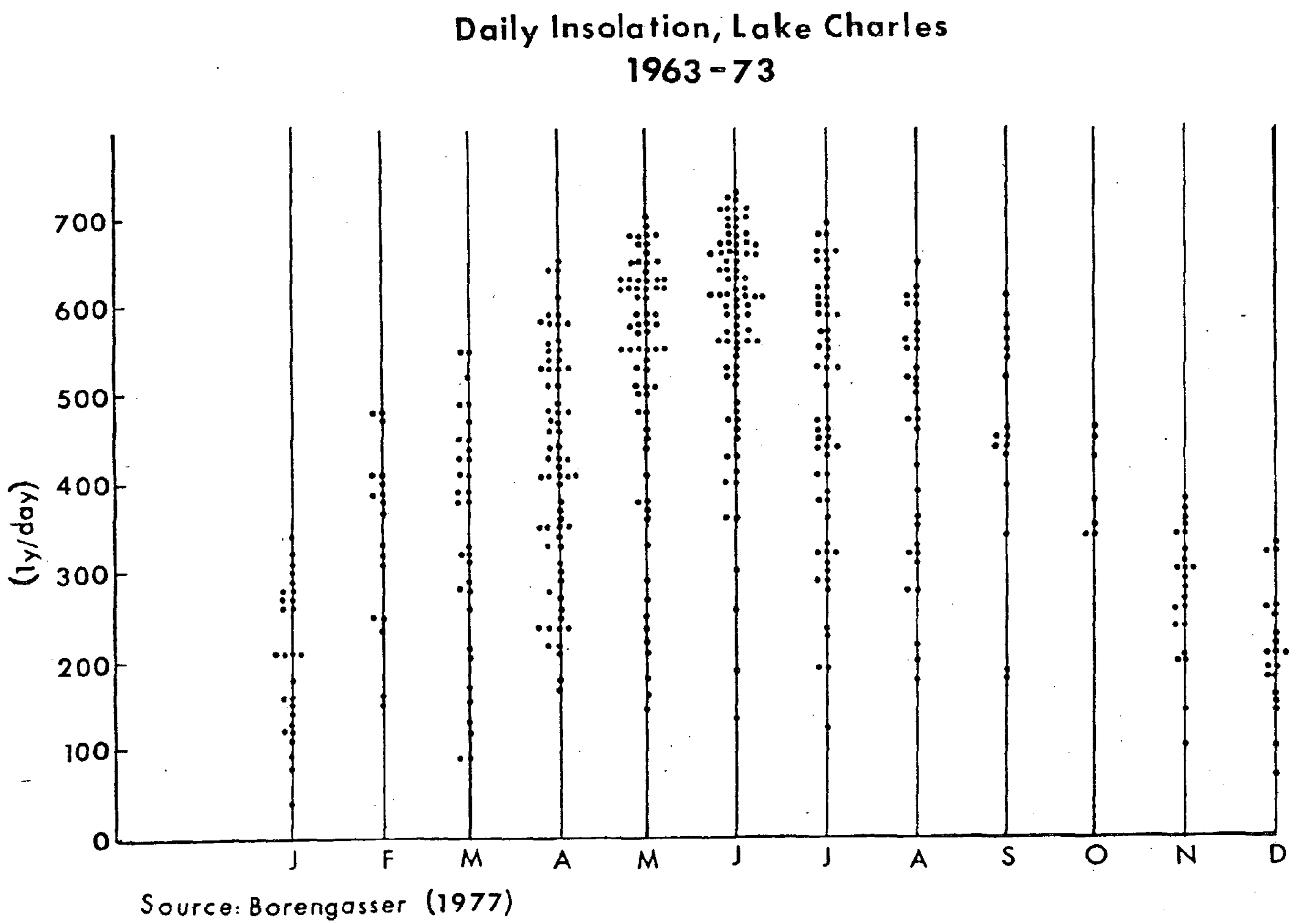


Fig. 2. Median daily insolation, Lake Charles, 1963-1973.



Source: Borengasser (1977)

Fig. 3. Daily insolation, Lake Charles, 1963-1973, for CH type.



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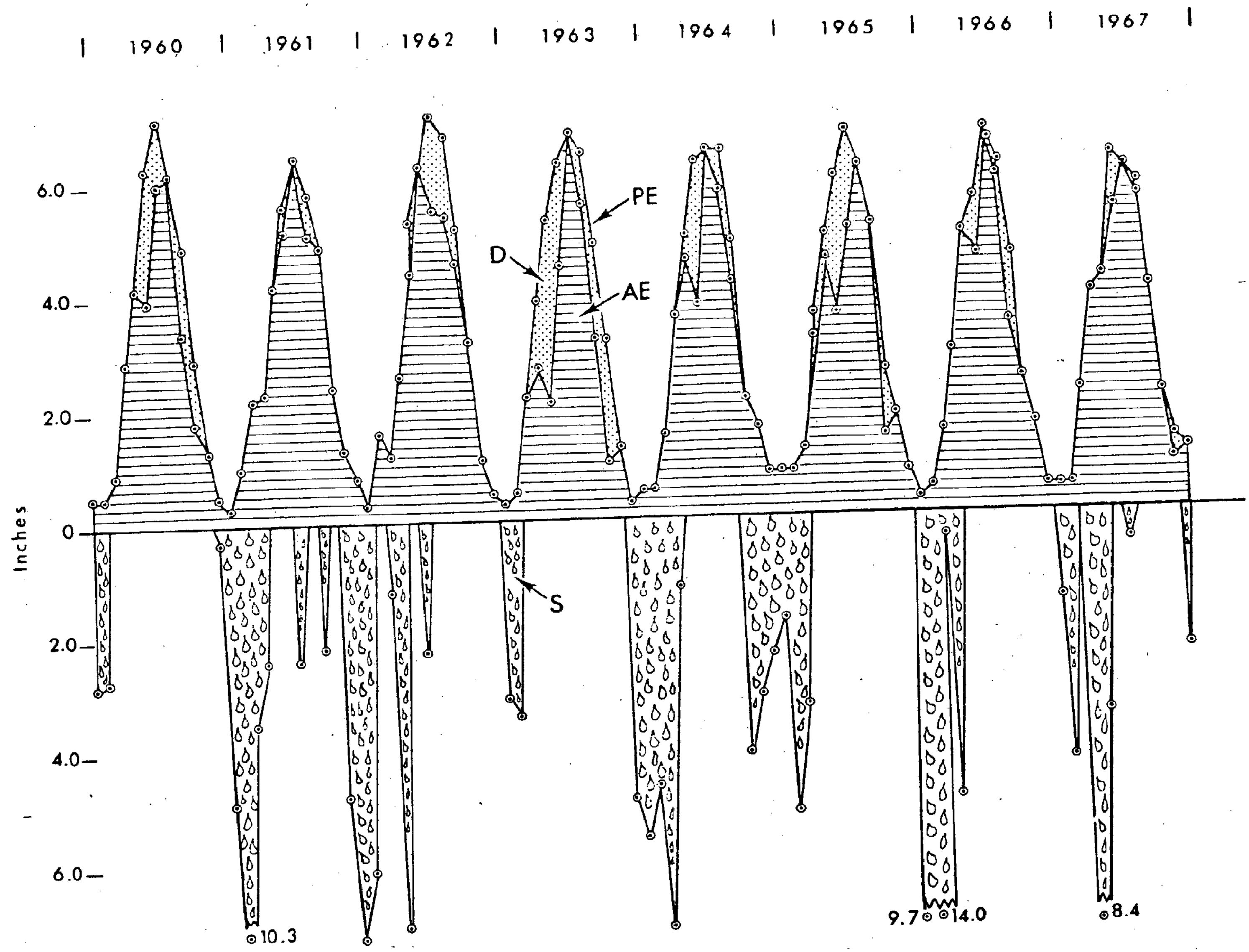


Fig. 5. Monthly course of computer water balance budget factors, potential evapotranspiration (PE), actual evaporation (AE), deficit (D), and surplus (S) at Baton Rouge, La. 1960-67 (from Muller and Larimore 1975).

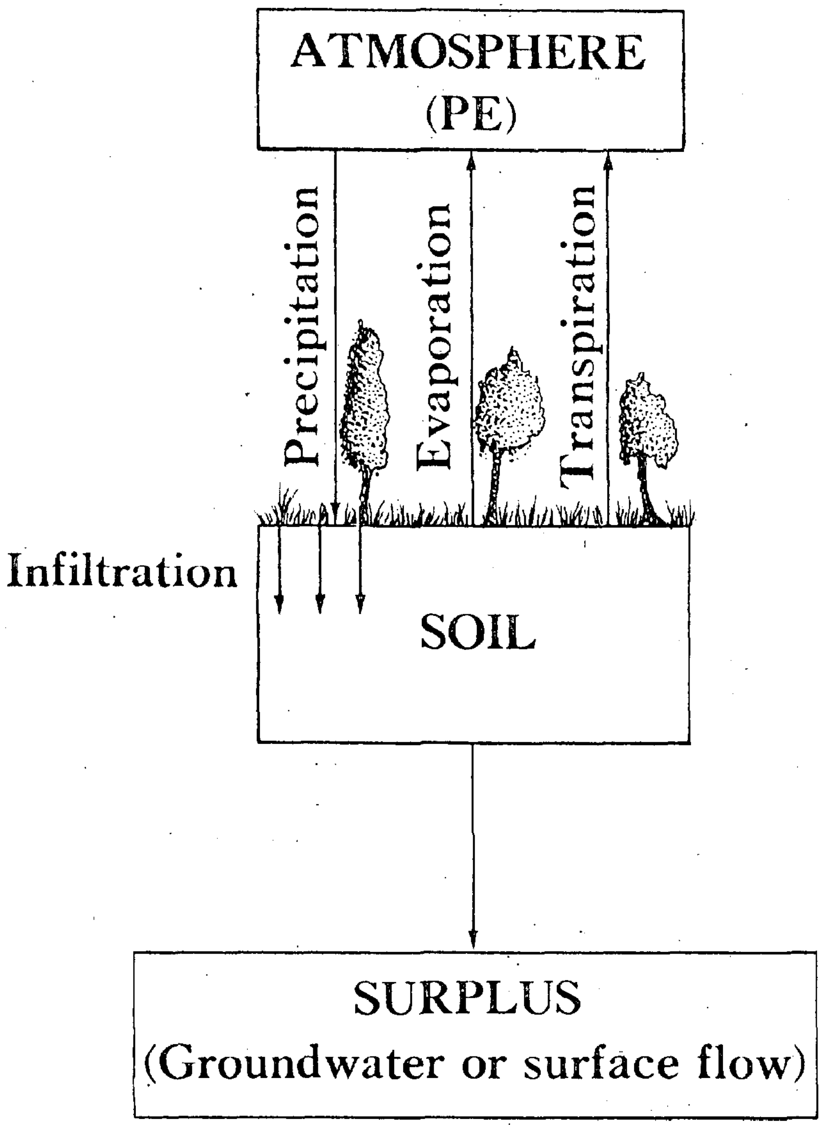
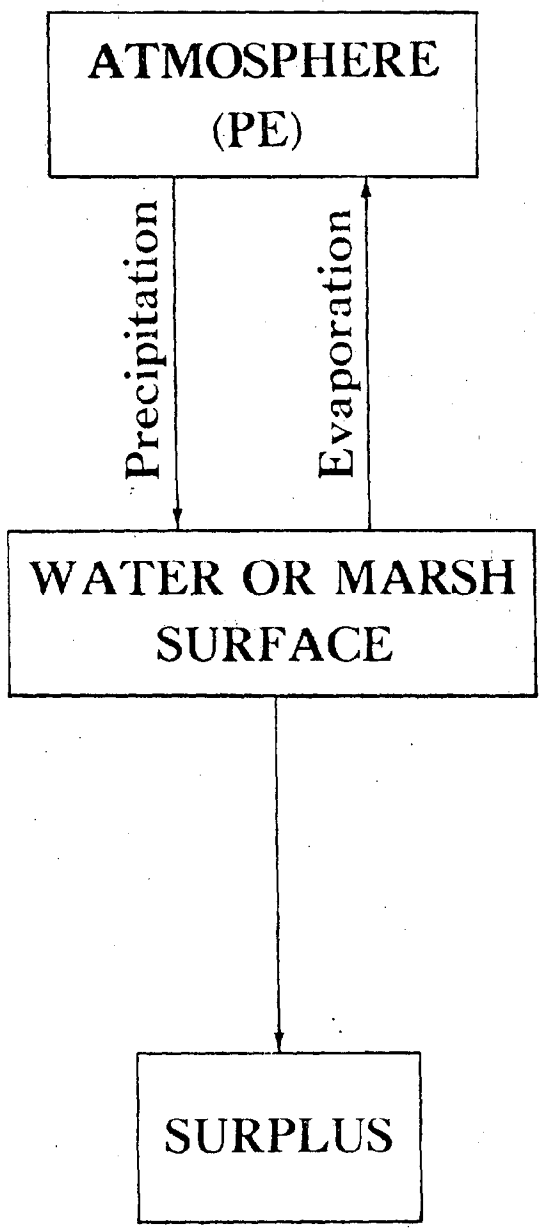


Fig. 6. Surplus calculation for well-drained surfaces (from Borengasser et al. 1977).



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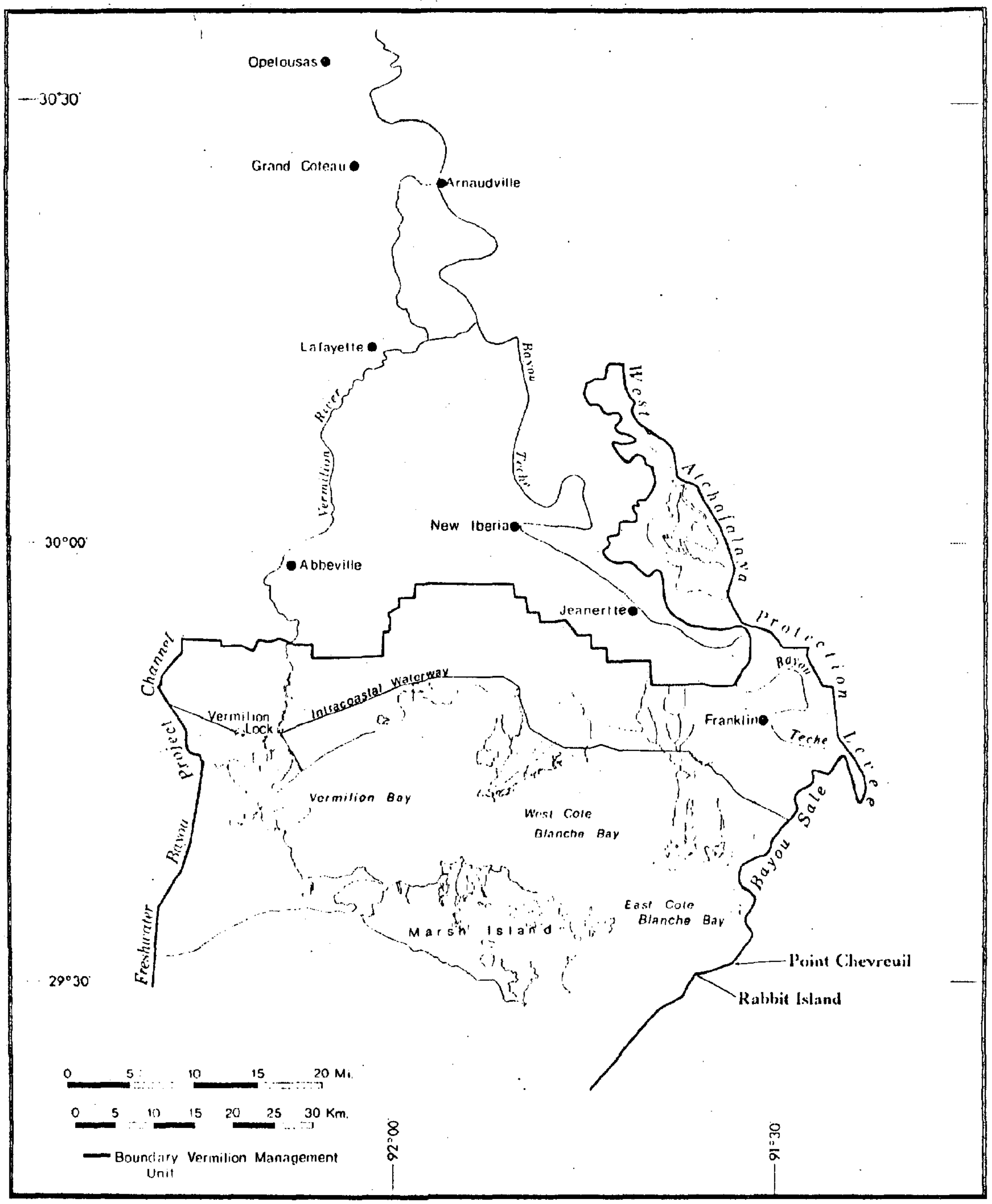

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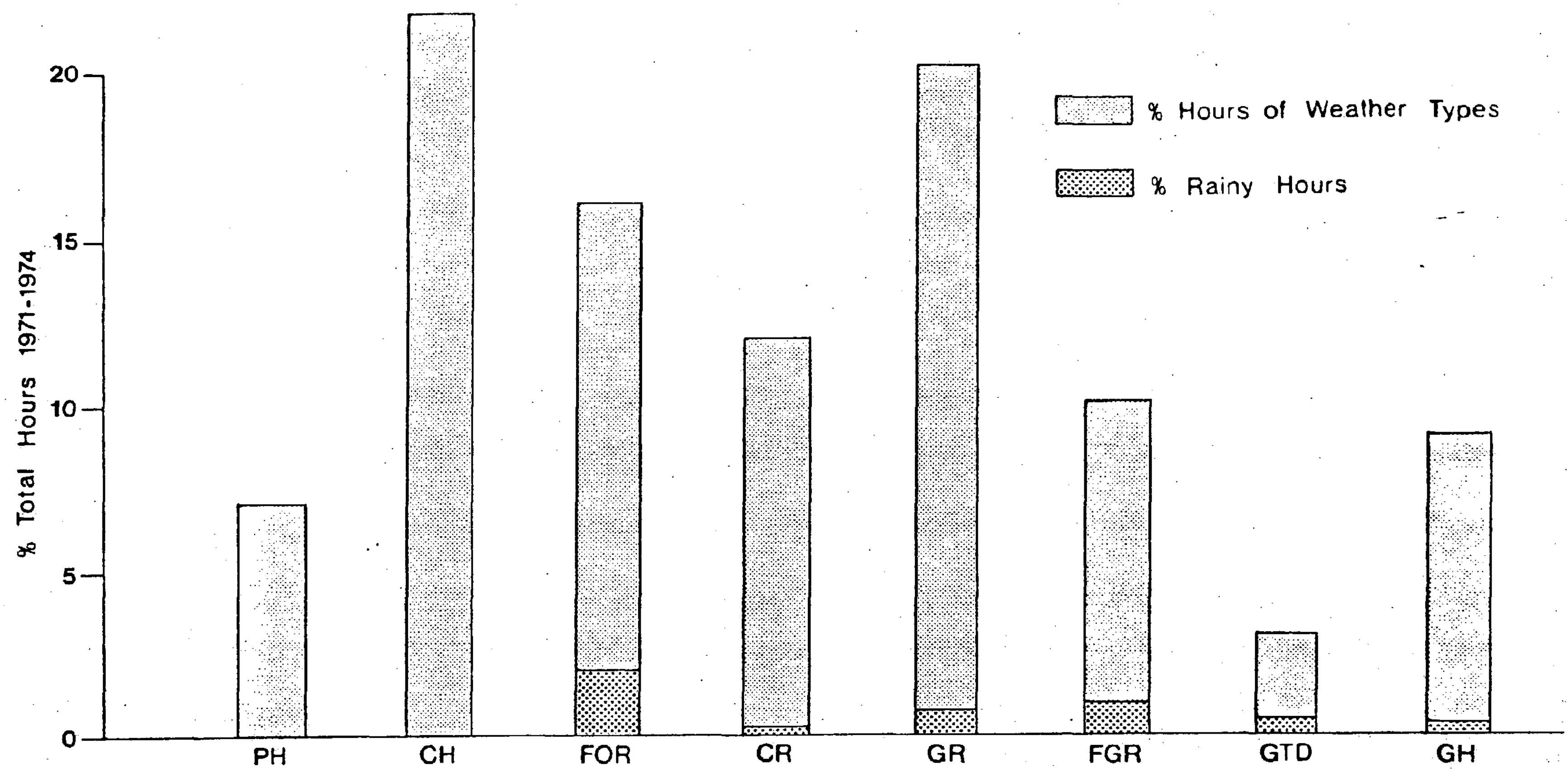


Fig. 9. Part A. Percent total hours and percent total precipitation, Lake Charles, 1971-1974. Part B follows.

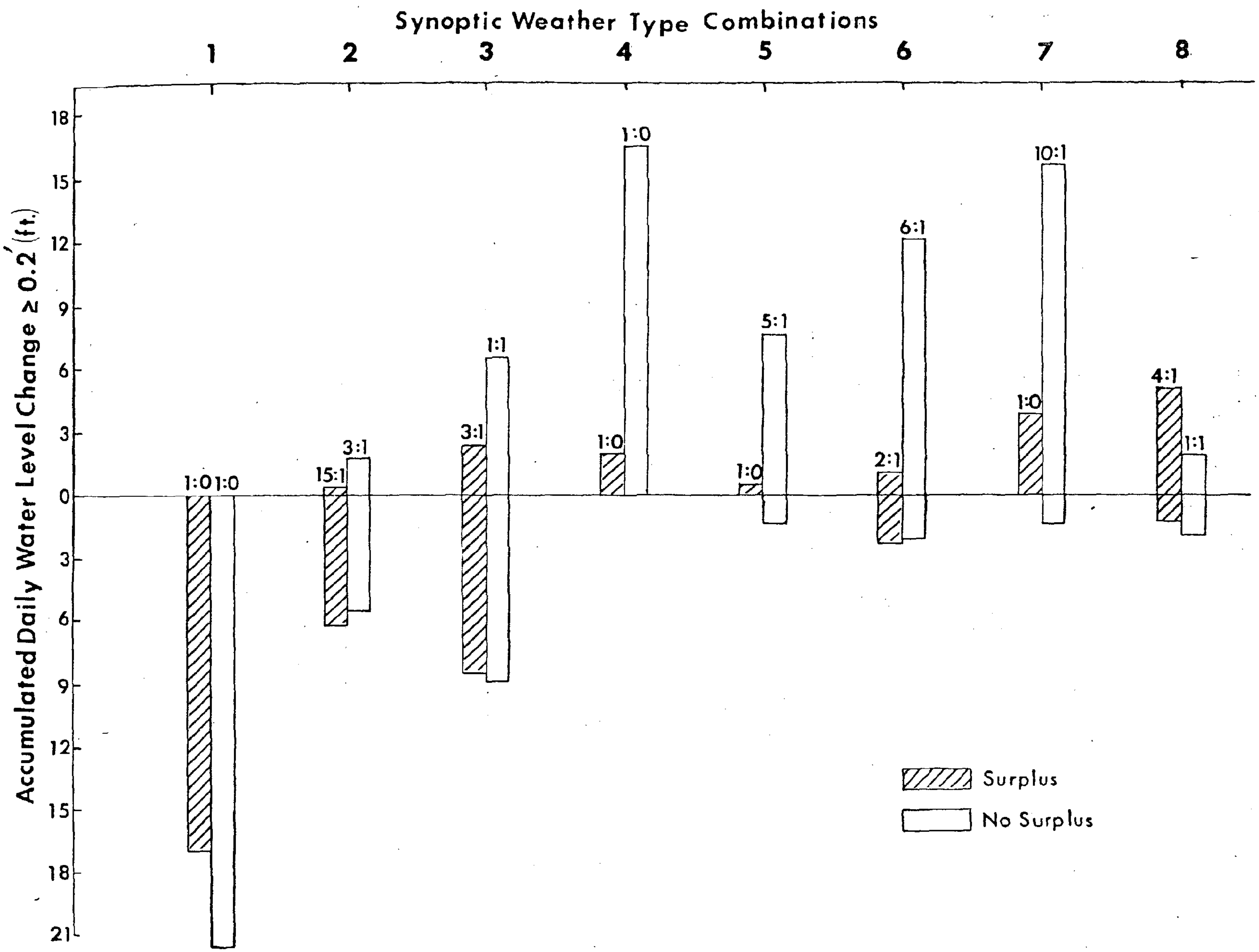
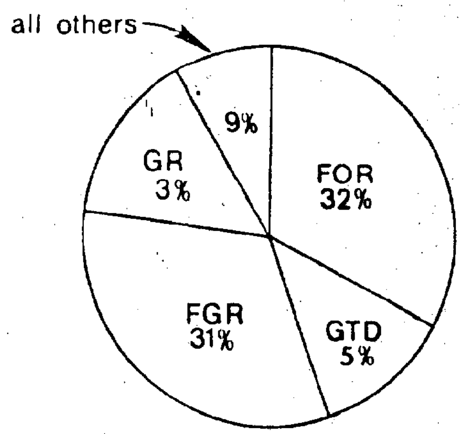


Fig. 10. Accumulated daily water level change tabulated by synoptic weather type combinations, Vermilion Lock, 1971.



% Total Precipitation Lake Charles, 1971-1974

Fig. 9. Part B.

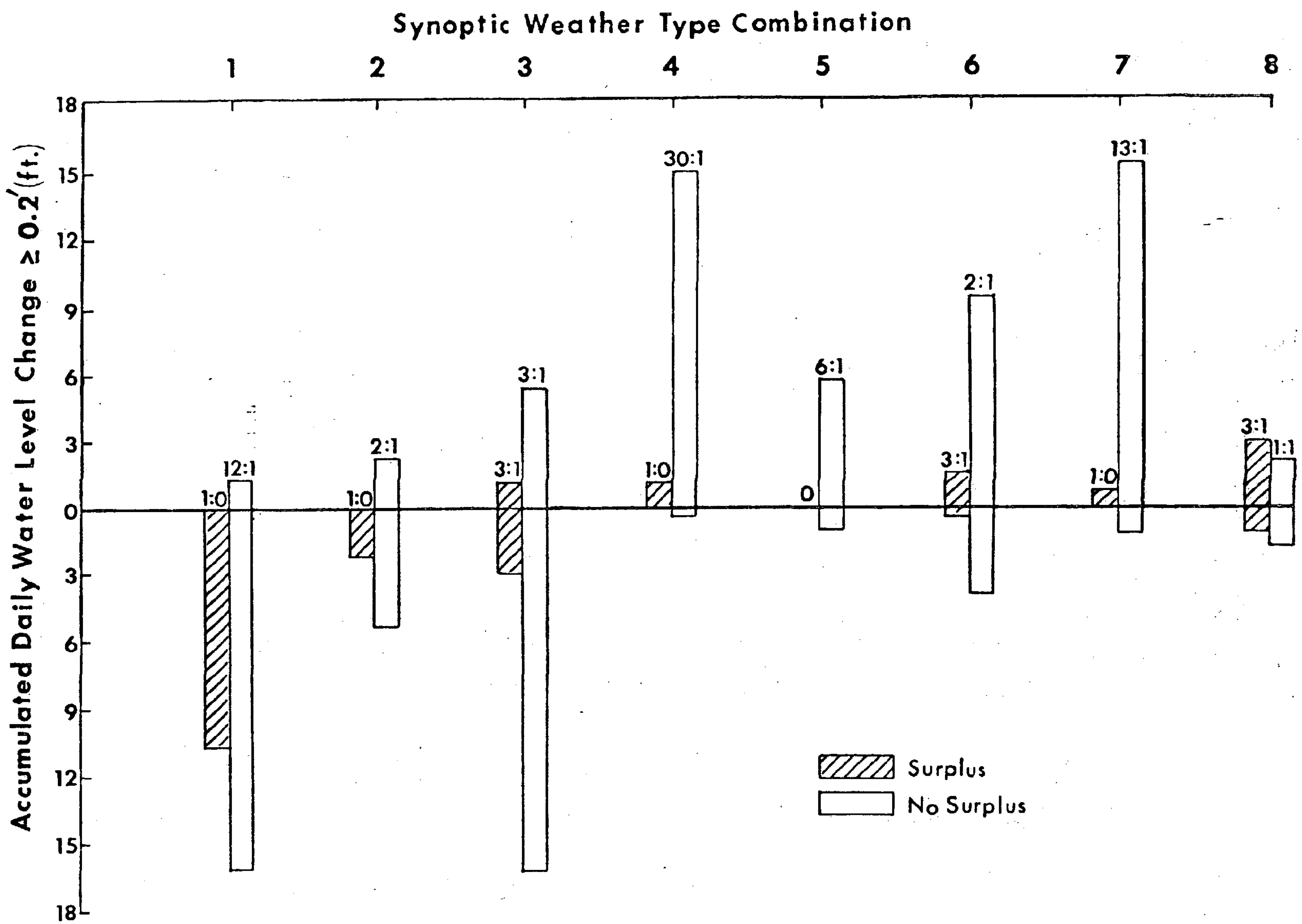


Fig. 11. Accumulated daily water level change tabulated by synoptic weather type combinations, Luke's Landing 1971.

TABLE 1
Mean Properties of Synoptic Weather Types,
Lake Charles, January 1971-1974

0600 CST	PH	CH	FOR	CR	GR	FGR	GTD	GH
NO. CASES	8	25	43	10	24	12	0	1
T_A	47	38	45	50	63	63	—	55
T_D	45	33	40	50	62	63	—	55
RH	92	85	87	98	97	99	—	100
WIND DIR.	06	02	01	12	17	17	—	15
WIND SPEED	7	7	11	6	9	8	—	5
CLOUD COVER	8	3	9	7	10	10	—	10
1500 CST								
NO. CASES	9	20	35	14	28	18	0	0
T_A	58	55	50	61	71	72	—	—
T_D	46	31	40	48	64	65	—	—
RH	66	43	75	64	80	81	—	—
WIND DIR.	36	02	03	12	17	19	—	—
WIND SPEED	8	10	13	10	15	13	—	—
CLOUD COVER	3	1	10	6	9	9	—	—

TABLE 2
Mean Monthly Precipitation by Synoptic Weather Types
Lake Charles: 1971-1974 In Inches

	J	F	M	A	M	J	J	A	S	O	N	D	YR	%
PH	0	0.1	0	0	0	0	0	0	0	0	0	0	0.1	
CH	0	0	0	0	0	0.4	0.5	0	0	0	0	0	0.9	2
FOR	4.5	1.0	2.0	2.1	1.5	0.5	0.4	0.8	0.2	2.2	2.4	1.7	19.3	32
CR	0.1	0	0	0	0.2	0.1	0.5	0.7	0.5	0.2	0	0	2.3	4
GR	0.9	0.2	0.1	0.7	1.4	0.6	1.1	1.5	0.8	0.2	0	0.1	7.6	13
FGR	0.9	1.9	1.2	1.4	3.2	0.5	0.1	0	0.7	1.6	1.6	5.2	18.3	31
GTD	0	0	0	0	1.0	0.2	0.2	1.2	6.4	0	0	0	9.0	15
GH	0	0	0	0	0	0.2	1.4	1.2	0	0	0	0	2.8	4
ALL TYPES	6.4	3.2	3.3	4.2	7.3	2.5	4.2	5.4	8.6	4.2	4.0	7.0	60.3	

TABLE 3
Insolation at Lake Charles, 1963-1973

(ly/day)

Month	January				Febuary				March				April			
Weather Type	N	$\bar{X}$	X	%	N	$\bar{X}$	X	%	N	$\bar{X}$	X	%	N	$\bar{X}$	X	%
CH	24	370	370	71	47	455	460	72	33	540	570	74	20	610	640	71
GH	4	370	360	69	6	470	450	70	2	540	540	70	5	550	550	61
PH	1	320	320	62	7	410	370	59	9	545	570	74	4	650	640	71
GR	28	200	210	40	18	340	380	59	33	365	380	49	74	420	430	48
CR	4	230	220	42	6	260	260	41	5	530	550	71	5	555	530	59
FGR	13	170	150	29	5	210	155	24	21	335	360	47	29	385	350	39
FOR	72	135	85	16	48	150	120	19	29	240	210	27	29	330	330	37
GTD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	146	200	-	38	137	315	-	49	137	400	-	52	166	435	-	48

N- number of cases

X- mean

X- median

%- percent of Angot's value (Solar radiation at the top of the atmosphere) for 30° N. Latitude

Source: Borengasser 1977b.

TABLE 3 Continued

Month	May				June				July				August			
Weather Type	N	$\bar{X}$	X	%	N	$\bar{X}$	X	%	N	$\bar{X}$	X	%	N	$\bar{X}$	X	%
CH	39	640	640	66	29	620	640	64	10	645	570	58	33	540	560	60
GH	13	605	600	62	54	545	630	63	86	535	570	58	68	510	540	58
PH	6	630	640	66	-	-	-	-	-	-	-	-	-	-	-	-
GR	74	520	560	58	82	580	610	61	60	480	475	48	35	440	470	51
CR	5	620	630	65	25	590	590	59	22	500	510	52	27	405	430	46
FGR	15	420	420	43	9	440	450	45	5	370	480	48	11	320	320	34
FOR	36	375	405	42	11	410	460	46	11	415	470	47	20	350	355	38
GTD	-	-	-	-	9	280	230	23	21	430	490	49	10	475	470	50
Total	188	520	-	54	219	565	-	57	225	475	-	48	203	465	-	50

Month	September				October				November				December			
Weather Type	N	$\bar{X}$	X	%	N	$\bar{X}$	X	%	N	$\bar{X}$	X	%	N	$\bar{X}$	X	%
CH	63	520	520	63	98	455	460	67	52	390	400	71	26	340	345	70
GH	5	500	530	65	12	440	450	65	3	315	350	63	6	315	325	66
PH	1	620	620	76	6	400	405	59	6	375	375	67	2	265	265	54
GR	17	455	450	55	7	395	380	55	23	275	290	52	20	210	210	42
CR	41	440	460	56	23	365	380	55	20	270	300	54	5	235	260	53
FGR	2	180	185	23	3	185	260	38	12	170	195	35	7	165	160	32
FOR	27	290	270	33	28	220	235	34	27	160	100	18	53	95	70	14
GTD	25	330	290	35	7	225	290	42	-	-	-	-	-	-	-	-
Total	181	430	-	52	184	390	-	56	140	297	-	53	119	193	-	40

TABLE 4

Climatic Stations, Station Weights, and Marsh vs. Nonmarsh Areas for the Ungaged Portion of the Vermilion Basin (Ungaged Basin Area 2082.9 mi^2)

Climatic Station Col. 1	Station Weight (%) Col. 2	% Nonmarsh Col. 3	% Marsh Col. 4
Franklin	28	16	84
New Iberia	19	50	50
Vermilion Lock	19	12	88
Lafayette FAA	11	100	0
Abbeville	11	100	0
Jeanerette	6	100	0
Grand Coteau	5	65	35
Opelousas	1	100	0
TOTAL	100	48	52

TABLE 5
Synoptic Weather Types, Percent of Hours, Lake Charles 1971-1974

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
PH	8	15	9	9	9	0	0	0	4	10	6	9	7
CH	18	22	18	21	28	19	10	21	16	40	27	25	22
FOR	31	19	19	13	11	11	5	7	14	13	29	30	16
CR	9	13	11	13	7	5	7	21	16	19	10	9	12
GR	20	16	24	29	26	25	29	18	18	11	15	10	20
FGR	13	15	19	15	14	10	2	2	6	8	13	19	11
GTD	0	0	0	0	1	2	5	6	24	0	0	0	3
GH	1	0	0	0	4	28	44	28	3	2	0	0	9
Continental Index (CH, FOR)	49	41	37	34	39	30	15	28	30	53	56	55	38
Tropical Index*(CR, GR, FGR, GH, GTD)	33	31	43	44	45	70	87	75	51	19	28	29	43
Frontal Index (FOR, FGR)	44	34	39	28	25	21	7	9	20	21	42	49	27
Storminess Index (FOR, FGR, GTD)	44	34	39	28	26	23	11	15	44	21	42	49	30

*CR - June through August only
GH - May through September only

TABLE 6
Mean Properties of Synoptic Weather Types,
Lake Charles, April: 1971-1974

0600 CST	PH	CH	FOR	CR	GR	FGR	GTD	GH
NO. CASES	13	30	15	16	33	13	0	0
T_A	53	50	61	56	67	67	—	—
T_D	51	47	58	54	66	66	—	—
RH	92	88	89	95	95	97	—	—
WIND DIR.	01	03	02	12	14	15	—	—
WIND SPEED	6	7	8	6	8	9	—	—
CLOUD COVER	1	2	9	5	9	10	—	—

1500 CST								
NO. CASES	9	22	17	16	37	19	0	0
T_A	77	74	72	74	77	76	—	—
T_D	48	45	58	53	66	67	—	—
RH	38	37	63	49	69	75	—	—
WIND DIR.	31	02	04	15	16	16	—	—
WIND SPEED	10	11	12	12	16	13	—	—
CLOUD COVER	1	2	9	4	8	8	—	—

TABLE 7
Mean Properties of Synoptic Weather Types,
Lake Charles, July: 1971-1974

0600 CST	PH	CH	FOR	CR	GR	FGR	GTD	GH
NO. CASES	0	13	5	9	34	2	5	56
T_A	—	73	74	73	76	76	74	75
T_D	—	71	72	71	73	74	71	73
RH	—	92	94	94	92	94	93	94
WIND DIR.	—	02	35	9	15	25	03	29
WIND SPEED	—	3	6	5	5	4	5	4
CLOUD COVER	—	7	9	3	7	5	6	5

1500 CST								
NO. CASES	0	12	5	7	36	3	6	55
T_A	—	84	81	84	87	91	85	88
T_D	—	73	73	74	74	73	71	73
RH	—	72	78	72	66	56	67	61
WIND DIR.	—	36	35	10	18	23	05	31
WIND SPEED	—	7	7	11	9	10	8	8
CLOUD COVER	—	8	10	8	8	8	8	6

TABLE 8
Mean Properties of Synoptic Weather Types,
Lake Charles, October: 1971-1974

<u>0600 CST</u>	PH	CH	FOR	CR	GR	FGR	GTD	GH
NO. CASES	12	53	15	22	12	8	0	2
T_A	60	59	66	67	70	72	—	68
T_D	58	56	64	65	69	70	—	67
RH	95	91	95	96	96	84	—	97
WIND DIR.	31	03	02	06	10	13	—	00
WIND SPEED	5	6	8	5	8	9	—	00
CLOUD COVER	3	3	9	3	6	9	—	5

<u>1500 CST</u>								
NO. CASES	11	45	16	24	13	13	0	2
T_A	79	80	70	83	84	79	—	84
T_D	58	76	63	64	69	70	—	66
RH	51	44	79	52	63	75	—	55
WIND DIR.	32	04	34	08	17	14	—	18
WIND SPEED	8	8	11	7	12	11	—	8
CLOUD COVER	3	3	9	4	6	8	—	5

TABLE 9
Annual Regime of Mean Properties for CH,
Lake Charles: 1971-1974

<u>0600 CST</u>	J	F	M	A	M	J	J	A	S	O	N	D
NO. CASES	25	29	23	30	37	25	13	26	18	53	35	34
T_A	37	44	46	50	63	71	73	71	68	59	46	40
T_D	32	31	41	47	60	68	71	67	66	56	41	36
RH	79	80	84	88	89	90	92	90	93	91	85	87
WIND DIR.	02	02	02	03	02	04	04	03	04	03	03	03
WIND SPEED	9	8	7	8	5	5	6	5	5	6	7	6
CLOUD COVER	3	2	3	2	3	5	7	3	3	3	1	2

<u>1500 CST</u>												
NO. CASES	20	24	22	22	34	19	12	25	29	45	32	27
T_A	55	57	66	74	82	87	84	90	82	80	65	60
T_D	31	31	39	45	59	62	65	67	63	56	41	38
RH	43	40	39	37	47	44	72	48	54	44	43	42
WIND DIR.	01	34	35	02	36	01	36	04	02	04	35	31
WIND SPEED	10	11	10	11	9	9	7	9	10	8	9	9
CLOUD COVER	1	1	2	2	4	5	8	4	3	3	2	2

TABLE 10
Annual Regime of Mean Properties for GR,
Lake Charles: 1971-1974

<u>0600 CST</u>	J	F	M	A	M	J	J	A	S	O	N	D
NO. CASES	24	15	26	33	33	28	34	18	22	12	14	11
T_A	63	57	63	67	70	76	76	74	74	70	62	61
T_D	62	56	61	66	68	72	73	73	72	69	61	60
RH	97	98	95	95	92	89	92	95	94	96	97	96
WIND DIR.	17	13	16	14	13	15	15	09	11	14	12	14
WIND SPEED	9	6	9	8	7	9	5	7	6	8	6	9
CLOUD COVER	10	4	9	9	7	7	7	7	4	6	6	9

<u>1500 CST</u>												
NO. CASES	28	20	30	37	32	32	26	18	22	13	17	12
T_A	71	72	73	77	79	86	87	83	85	84	80	71
T_D	64	59	62	66	69	73	74	74	74	69	67	63
RH	80	67	71	69	70	66	66	75	69	63	65	78
WIND DIR.	17	18	17	16	16	17	18	19	17	17	18	15
WIND SPEED	13	15	14	16	14	13	9	8	10	12	11	12
CLOUD COVER	9	7	8	8	8	7	8	9	6	6	5	6

TABLE 11
Percent Rainy Hours by Synoptic Weather Types,
Lake Charles: 1971–1974

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
PH	0	1	0	0	0	0	0	0	0	3	0	0	0
CH	0	0	0	0	0	1	3	0	1	0	1	0	0
FOR	19	9	11	12	12	3	8	6	8	21	13	9	11
CR	1				2	1	1	4	3				2
GR	6	1	1	4	3	3	6	15	6	3		3	4
FGR	10	14	8	12	18	2	2	2	15	15	11	17	11
GTD	0	0	0	0	13	3	1	8	18	0	0	0	18
GH	0	0	0	0	0	1	3	4	1	3	0	0	3

TABLE 12
Selected Mean Properties of Synoptic Weather Types at Lake Charles, 1971-1974*

	Wind Direction/ Speed		Cloud Cover		% Mean Annual Precipi-tation
	Jan	July	Jan	July	
Gulf High (GH)	—	26/6	—	5	4
Pacific High (PH)	35/7	—	3	—	0
Continental High (CH)	01/8	05/6	2	6	2
Frontal Over-running (FOR)	02/10	36/6	10	9	32
Coastal Return (CR)	12/7	08/8	5	6	4
Gulf Return (GR)	16/7	17/7	9	7	13
Frontal Gulf Return (FGR)	17/10	24/6	9	5	31
Gulf Tropical Disturbance (GTD)	—	05/7	—	6	15

*Wind direction in ten degrees of azimuth from 01 (10° = NNE) through 18 (180° = south) to 36 (360° = north). Wind speed in knots. Cloud cover on a scale of 0 (clear) through 10 (cloudy).

TABLE 13
Summary of Response Characteristics
of Individual Locations

Location	Number of Observations		Mean Responses(ft)		Range of Responses (ft)		% Anticipated Responses
	NS	S	NS	S	NS	S	
Luke's Landing	189	41	.05	-.23	-1.90 to 1.90	-2.50 to 1.10	84%
Vermilion Lock	185	77	.10	-.25	-1.90 to 1.80	-2.50 to 1.70	84%

(modified from Wax, 1977)

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Part II • Vermilion Basin: Hydrologic and Hydrographic Processes

by P. A. Byrne

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Part II

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ACKNOWLEDGMENTS

Efforts toward implementation of coastal zone management in Louisiana have enlisted the interest and particpitation of many public agencies and institutions. As a cornerstone for this program, scientific information from every available source is being compiled and digested in a series of Coastal Zone Management reports. The collection is ultimately intended as an authoritative central reference source for persons involved in administration of an operational CZM program.

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INTRODUCTION

The Vermilion Basin exists in its present configuration as the result of natural processes and man's efforts to control the natural system: control through digging canals, dredging existing waterways, and building water control structures. By using available data with its limitations we hope to document the historical interaction of riverine processes, tidal exchange, gulf level variations, and the manipulation of existing water control structures. When used in conjunction with the climatological characterization presented in Part I, this information should form a baseline of information which demonstrates how this system generally functions through periods of varying climatic and hydrographic regimes. It should also provide a framework from which to build an effective research program; it should furnish insights into water management schemes for comparing and working with other management considerations affecting the Coastal Zone.

Water levels, currents, and meteorologic driving forces are critical dynamic phenomena that govern circulation and exchange of estuarine waters in Louisiana's coastal zone. These factors are especially critical in the basins adjacent to accelerated deltaic growth. In these areas wetland maintenance and productivity are enhanced by the introduction of inorganic sediments. The interaction of basin hydrography and primary productivity is directly reflected in the abundance and distribution of fish and wildlife. Increased emphasis on the hydrologic basin as a discrete environmental unit has prompted a systematic approach to the study of the coastal ecosystem.

The Vermilion Basin Management Unit (Fig. 1) is in a complex dynamic and highly impacted area. On the east flank of the Basin the

Lower Atchafalaya River pours massive amounts of fresh water and sediments into the Vermilion-Atchafalaya complex and threatens to cut off the Cote Blanche Bay system from the gulf by rapid deltaic progradation.

On the west side of Vermilion Basin, exchange from the adjacent marshlands and water bodies has been cut off or at least moderated by locks and dams. White Lake, once a productive shrimp nursery ground, is now a vast reservoir of almost fresh water for rice farmers; its capacity for contribution to estuarine productivity has been reduced substantially.

Hydrologic processes operating within the coastal basin are best described through the use of numerical hydrodynamic models based on quantitative circulation and exchange studies. Such data are not available for the Vermilion Basin and are beyond the scope of this investigation. Therefore, efforts to characterize seasonal and long-term trends in basin hydrography have been restricted by the small amount of available water level, salinity, and temperature data that have been taken in the Vermilion Basin. However, variable amounts and quality of data covering the past 30 years are available. These existing data were collected primarily by the U.S. Army Engineers (CE), New Orleans District, and the Louisiana Department of Wildlife and Fisheries. Location of stations (Fig. 1) and frequency of sampling have afforded initial comparisons and are enhanced by consistent methodology and repeating techniques.

The impact of man in the Vermilion Basin has been dictated by the need for freshwater supply to irrigate rice fields in the area. In meeting this requirement extensive systems of water control structures were installed (Fig. 1). This has resulted in interruption of the normal estuarine/marshland nutrient cycle through periodic blockage of water circulation between marsh habitats and Vermilion Bay.

BASIN HYDROLOGY AND HYDROGRAPHY

Riverine Processes

Drainage Basin

The Vermilion Basin Management Unit is the southernmost area drained by the Vermilion River and the Bayou Teche drainage systems. At the present time these systems are connected and this has been augmented by numerous diversion canals, locks, and control structures.

The Vermilion River and Bayou Teche have a total drainage of about 2,500 square miles; some 1,600 square miles of this is drained by Bayou Teche. The watershed of both streams lies in south-central Louisiana and extends 150 miles from the Red River to the Gulf of Mexico. The upper 1,600 square miles is drained by Bayous Rapides, Boeuf, and Cocodrie on the west and the upper portion of the Atchafalaya Basin protection levee on the east. Bayou Teche heads in Bayou Courtableau at Port Barre. There is controlled diversion at times of overflow from the Red River and Old River, Bayou des Glaises, and Big Darbonne Bayou Culvert, which flows through the Bayou Courtableau drainage structure. In addition, Bayou Fusilier may interchange flow between Bayou Teche and the Vermilion River depending on the gradient between them. Bayou Teche also supplies irrigation water to the Vermilion River via Ruth Canal.

Bayou Teche and the West Atchafalaya Basin Protection Levee (WABPL) Borrow Pit drains the area south of Bayou Courtableau. The drainage through this area flows south through Lake Fausse Pointe into Bayou Teche and through Charenton Drainage Canal Floodgate to the Charenton Drainage Canal into West Cote Blanche Bay.

The Vermilion River drainage arises through many small tributaries such as Bayous Coulee Mine, Vermilion, St. Clair, Bourbeaux, Fusilier, and Pont Brule. South of Lafayette more tributaries enter the Vermilion River and contribute local drainage. These are Cypress Bayou, La Salle Coulee, Parcperdue Coulee, and King Anselm Coulee, to name a few. Local drainage is noticeably east-west with the Vermilion River flowing south in an entrenched channel through Pleistocene sediments. (The U.S. Geological Survey 1:250,000 maps NH 15-6, NH 15-8, NH 15-9 contain drainage system information that is too detailed to present at a scale which could be incorporated into this report.)

The Lower Vermilion River begins at Lafayette and ends at Vermilion Bay adjacent to Mud Point. The river has high banks and a well defined stream valley, a result of the Vermilion's taking over what was probably an abandoned Mississippi River channel. Local drainage below Abbeville is southward. The Intracoastal Canal cuts across the lower end of the Vermilion Basin Management Unit, adding drainage waters from adjacent parishes to the waters of the Vermilion River at 2.2 and 3.5 miles above the mouth (Kazman 1965).

The Vermilion River is tidal as far inland as Abbeville, and on occasion salinity intrudes this far inland. Ground water in the area is sometimes recharged by Vermilion River water and vice versa during various stages of river flow and ground water conditions (Jones et al. 1954).

The third drainage system of the Vermilion Basin Management Unit is the Fresh Water Bayou/Schooner Bayou system in the southwestern section of the Basin. The entire region is tidally influenced and natural drainage patterns are unclear because of the large numbers of man-made canals.

River Discharge

Daily discharge of the Vermilion River (USGS 1975) rarely exceeds 2,500 cfs., with most days recording a discharge of under 1,000 cfs. (Fig. 2). Ruth Canal makes a very small contribution to the Vermilion River with discharges that average less than 300 cfs. The long-term mean discharge for the Vermilion River at Lafayette (Surrey Street gage) is 621 cfs. The rise and fall of the tide has an effect on discharge past this point. The tidal pressure gradient is frequently sufficiently strong to overcome the stream head.

Discharge of Bayou Teche water through Keystone Lock and Dam (483 cfs. average for 14-year record) is lower than that of the Vermilion River. There are no discharge records for the Schooner Bayou/Fresh Water Bayou system.

In general, river discharge is highest in the spring, but for the Vermilion River during any given year this may not be the case. For example, Figure 2 demonstrates that maximum discharges can occur during almost any month. Heavy rainfall associated with storms at various times of the year is a contributing factor. In 1971 two hurricanes affected the area during September thus altering the normal pattern. The variability of river discharge is shown by comparing the 1968 and 1969 records (Fig. 2). Monthly river discharge for the Vermilion River is highly variable when compared to other river basins in coastal Louisiana. This is attributed to the quick runoff characteristics of the relatively small upland drainage area. Dispersal of river water is minimal until the Vermilion River intersects with the Gulf Intracoastal Waterway and Vermilion Cutoff to the Vermilion Bay. Other local river basins in coastal Louisiana may also have these same characteristics, however, lack of sufficient data precludes closer examination.

Surface Water Slope

Surface water slopes have been determined for the Vermilion River, Bayou Teche, and the Fresh Water/Schooner Bayou system (Fig. 3). Average slopes for the Vermilion River is 0.066 ft/mile, while the Fresh Water Bayou/Schooner Bayou average slope is 0.015 ft/mile. Average surface water slope for Bayou Teche is 0.14 ft/mile.

The average values should not, however, indicate that there is a consistent slope over the entire gaged distance. For example, the surface water slope is steepest between the two Fresh Water Bayou stations, which are 0.5 mile apart. This is due to the presence of a water control structure north of the southernmost gage. Surface water slopes are high between Arnaudville on Bayou Teche and Charenton Drainage Canal. There are two water control structures along this section that artificially maintain high water levels behind the lock or dam.

Seasonal Water Levels

The first seasonal water level patterns at Ruth and Arnaudville (Fig. 4) do not reflect the patterns observed nearer to the coast. These patterns are dominated by river discharge; southerly winds play a less significant role in determining annual and semiannual water level cycles.

Tidal Processes

Spatial Variation in Tides

Relationships between concurrent tide ranges at several stations were investigated (Fig. 5). In general, 84 percent of the variation in the tide at Luke's Landing can be attributed to variation in the tide at Eugene Island. Thus 16 percent of the variation in tide range is due to factors such as bottom topography winds, precipitation and interference by oyster reefs or channel configuration. The tide range at Eugene Island is 8 percent attenuated over a distance of 17 miles to Luke's Landing, resulting in an average attenuation of 0.47 percent/mile. There is a good relationship between the tide ranges at the two stations, which indicates that the tide enters East Cote Blanche Bay via Atchafalaya Bay with lag increasing progressively to Luke's Landing (lag time of 1.1 hours with a standard deviation of 1.17 hours).

The same relationship between concurrent tide ranges at Luke's Landing and Vermilion Lock were investigated (Fig. 5). The linear relationship accounts for only 56 percent of the variation at Vermilion Lock, indicating that almost half of the variation in tide range is caused by other factors. The lag time between Vermilion Lock and Eugene Island was 4.5 hours with a standard deviation of 2.6 hours (Fig. 6), however, there was not always an increasing lag between Luke's Landing and Vermilion Lock. This analysis showed that, at times, the tide arrived at Vermilion Lock before or at the same time as at Luke's Landing. This indicates tidal influence through Southwest Pass into Vermilion Bay. Because there are no other data available at this time, the only thing that can be said is that there may be two or more tidal regimes in the Vermilion Basin. The Schooner Bayou/Fresh Water Bayou regime, Southwest Pass/Vermilion Bay regime, and Atchafalaya/East and West Cote Blanche Bay regime. These regimes will be similar in nature but will cause constructive and destructive interference in areas where they propagate and will probably set up unusual circulation patterns within the estuaries.

The progression and shape variation of the tidal wave along the coastline of Louisiana and east Texas is shown in Figure 7. The diurnal tide described for Barataria Bay (Byrne et al. 1976) is not evident in southwest Louisiana. The progression of the tidal wave from east to west is maintained through Calcasieu Pass. Beyond this point the tidal wave progresses from west to east as indicated by the curves for Sabine Pass and East Bay, Tex.

Short-Term Tidal Patterns

Tide range varies a great deal within a two week period, although mean monthly values do not show this. This variability appears in several ways: a section of the tide record for a two-week period shows that the tide varies in height every day (Figs. 8 and 9). Furthermore, when there are two tides per day these tides are smaller in range than when there is only one tide per day. Although the ranges of the semi-diurnal tide are smaller than those of the diurnal tide, there is no absolute relationship between the range of the tide and the absolute height relative to mean sea level. Therefore if water levels are high, a small amplitude tide may be just as effective at flushing the marsh as a large amplitude tide during a period of low water levels.

Seasonal Tide Range

Tides in Vermilion Basin are to a large extent diurnal; that is, there is one high and one low water during a tidal day. Figures 8 and 9 depict the fortnightly (biweekly) pattern and the progression upstream.

The harmonic constituent ratio for this section of coastal Louisiana is 2.95 (harmonic ratio-diurnal tidal forces compared to semidiurnal forces in terms of tidal energy, i.e., if the ratio is equal to or greater than 3, there will be only one tide per day--ratios less than 3 indicate two tides per day); the sum of the diurnal forces is 2.95 times as large as the sum of the semidiurnal forces. This results in a record in which diurnal tides occur half of the time, and semidiurnal tides the remaining half (per 1971). This compares to the 100 percent or total semidiurnal record in the Calcasieu estuary, and the 20 percent semidiurnal/80 percent diurnal record for the Barataria estuary. Over a long period of time, say, 9 years, the percentage of those relative to each other will shift.

The mean semidiurnal tide range for 1971 at Vermilion Lock is 1.23 feet. During 1963 the mean tide range at Bancker was 1.02 feet. Only two weeks of usable record was available for 1971 at Bancker, so there is no estimate of mean tide range for 1971. However, if it is assumed that 1971 was a year of maximum tide range at Vermilion Lock and 1963 was pretty close to the minimum tide range at Bancker (per 18.6 year tide range cycle), then the attenuation between the two stations would never exceed 17 percent, and more than likely it would be less than this figure.

No tide data are available farther up the Vermilion River, however, Abbeville is considered tidal and at times river discharge and stage at the Lafayette station (Surrey Ave. Bridge) is affected by tides, causing currents to reverse and flow upstream (USGS 1975). Mean tide range for Schooner Bayou for 1971 was 1.29 feet, slightly higher than the tide range at Vermilion Lock.

Within a year trends are slight in this area. A 14-year mean monthly tide range for Schooner Bayou and a 1-year monthly mean for Vermilion Lock was plotted (Fig. 11). The Schooner Bayou profile has minimum tide range during March-April and August-September while Vermilion Lock shows lower values for all months excluding winter months. From this it may be inferred that winds and precipitation interfere with astronomical expression of tides, causing the mean monthly tide range to deviate from long-term expected mean values.

Long-Term Tidal Patterns

Tide range may vary with time over a number of years; as an example, a 19-year tide range cycle was found at Bayou Rigaud (Marmer 1954). This same relationship, although not a monotonic rise over the same period, is observed in a plot of Schooner Bayou mean annual diurnal tide range for the period 1958-1971 (Fig. 12). Long-term trends at Bayou Rigaud were plotted for comparison purposes. The difference between the maximum value and the minimum value is 0.5 feet, a value that is larger than the difference at Bayou Rigaud of 0.39 feet. This results in a 45 percent variation about an overall mean value of 1.10 feet at Schooner Bayou. This is larger than the 39 percent variation about the 1.0 foot mean tide range at Bayou Rigaud.

<u>Gulf Water Level Variations</u>

Seasonal Water Levels

Seasonal water levels have been computed for all stations in the Vermilion Basin. Five distinct patterns of long term mean water level are discernible:

- Bayou Teche at Ruth and at Arnaudville was discussed under riverine processes. These stations have a pattern that parallels river discharge (Fig. 4).
- Vermilion Lock, Schooner Bayou, Fresh Water Bayou North, and Bancker (Fig. 13) have a semiannual cycle with two unequal maximums occurring in May and September with minimums in July and December. The September maximum is the primary peak and is unrelated to river discharge. The July minimum described in the Barataria estuary (Byrne et al. 1976) is not pronounced here, however, the January minimum is the primary low in both the Barataria and Vermilion basins. This pattern observed at the Vermilion Lock station indicates the lack of a significant river discharge contribution as opposed to the September circulation effect. This is likely due to the small watershed and inadequate water storage capabilities in the Basin.
- Luke's Landing (Fig. 13) has two maximums of equal intensity. However, the July minimum observed at Vermilion Lock and other stations is absent here.
- Charenton Drainage Canal (Fig. 13) shows that the time of maximum water levels have approximately the same intensity; however the July minimum is more developed than at Luke's Landing.
- Fresh Water Bayou South (Fig. 13) exhibits a large spring maximum that never develops into a July minimum. The September maximum is visible, however, it is overshadowed by the spring maximum. It is possible that the effect of the more buoyant fresh water from the Atchafalaya and Mississippi rivers result in higher water levels near the coast during June. This effect overshadows the normal semiannual cycle that is present on the north side of the lock only a half mile away.

The two Fresh Water Bayou stations (Fig. 13) show the effect of lock operation. Aside from the distinctly different water level patterns, water levels are higher behind the lock from August through April and are as much as 1.0 to 1.5 feet higher during this period. From April through August water levels are about one-half to seven-tenths of a foot lower than coastal waters, thus the lock succeeds in preventing encroachment of higher saline water into the Basin.

Seasonal cycles of water levels are important for several reasons. The spring peak represents excess fresh water (precipitation) runoff, and the effects on the overall annual cycle are evident. When water levels lower in mid summer as shown at some stations, fresh/salt water mxing occurs, but flushing associated with water level drop is not apparent at all stations. Following mixing of the fresh water, the flushing cycle is reversed, which results in increased salinities and water levels in the estuaries. High salinity water slowly circulates back into the Vermilion-Atchafalaya estuary. This in turn is flushed out by the January minimum and the cycle starts again with the spring freshet.

The most oustanding feature of these cycles is the apparent slowness with which high water levels are drained out into the gulf (Fig. 13). This is enhanced by the almost complete closure of Vermilion Bay from the gulf. Water level variability is similar for all stations in the Vermilion Basin. In general a measure of variability was obtained by calculating the mean monthly standard deviation. Monthly standard deviation is at a minimum during the summer months and is high during fall, winter, and spring. This can be directly related to climatologic factors, primarily frontal passages. When a front approaches the coast brisk southerly circulation occurs followed by a rapid reversal (winds from the north) as the front moves out over the gulf (Wax et al. 1977).

This wind system results in dramatic changes in water levels that sometimes are dominant over tides within the estuaries. In general, water levels increase with southerly winds and decrease with the northerly winds.

Apparent Long-Term Sea Level Trends

Long-term water level trends were computed for all stations in the Vermilion Basin Management Unit using a linear regression. All stations exhibit essentially the same increasing trend despite the fact that some stations are in impounded areas behind weirs and dams. Records dating from 1945 (US Army Engineers 1935-1977) were used to determine an average increase of 0.03 ft/year in apparent water levels at Schooner Bayou (Fig. 14). The same technique was performed on the other stations for the period 1963-1974 (Fig. 15). In all cases the apparent water level increase rate ranged from 0.029 ft/yr to 0.107 feet per year. A striking feature of this increase is that all stations exhibit basically the same trend with positive and negative deviations occurring during the same years. To date there is no one acceptable theory that explains these trends that appear consistent in this one respect.

Frequency and Duration of Marsh Inundation

The frequency and duration of marsh inundation is directly related to flushing and water renewal. In order to estimate marsh inundation characteristics, an assumption was made from interviews with the scientific and nonscientific community. This assumption is that the marsh surface maintains its level in respect to local mean high water over a given period of time. Thus the number of times per month, the total hours per month, and the mean time that water levels exceeded the marsh datum can be determined. Even if the datum is not precise the proportions of time will remain approximately the same.

The frequency and duration of water levels dropping below mean low water (MLW), rising above mean high water (MHW), and reaching levels one-half foot above MHW are shown in Table 1. In general, for 1971 water levels fell below MLW 22.1 percent of the year, rose above MHW 29.3 percent of the year, and exceeded MHW plus 0.5 foot 10.6 percent of the year. This is considerably different from Bayou Rigaud, where water levels exceed MHW 12 percent of the year and MHW plus 0.5 ft, 2.0 percent of the year.

Water levels rising above MHW at Vermilion Lock occur 230 times/yr. This rate is twice that of Bayou Rigaud (128 times/year) and reached or exceeded the +0.5 foot level almost four times more.

These frequencies and durations of water level oscillation are not randomly distributed throughout the year. In January, March, June, and July the average is over 200 hours per month of water levels below MLW, while in September, October, and December the average extends over 300 hours per month of water levels in excess of MHW; in September and December the average is over 185 hours of water levels 0.5 foot above MHW. In all cases the frequency of these events increases as total hours increases.

The implication of these figures is that water levels cause frequent flushing of the marsh during two periods of the year: September,

TABLE 1. The frequency and duration of water levels dropping below MLW, rising above MHW, and reaching MHW + .05 at Vermilion Lock.

Variables	J	F	M	A	M	J	J	A	S	O	N	D	Total for 1971
Below MLW (Hours)	297	219	264	231	132	240	231	126	9	42	117	30	1938
Frequency (# of events)	20	13	17	19	14	26	25	18	2	7	13	5	179.0
% of month	39.9	32.6	35.5	32.1	17.7	33.3	31.1	16.9	1.25	5.6	16.3	4.0	22.1
Mean time/event (hr)	14.8	16.9	15.5	12.2	9.4	9.2	9.2	7.0	4.5	6.0	9	6	10.83
Above MHW (Hours)	92	180	177	221	224	42	86	80	482	327	242	417	2570
Frequency (# of events)	12	17	22	19	17	11	10	13	25	32	22	30	230
% of month	12.4	26.8	23.8	30.7	30.1	5.8	11.56	10.8	66.9	43.9	33.6	56.1	29.3
Mean time/event (hr)	7.6	10.6	8.0	11.6	3.2	3.8	8.6	6.2	19.3	10.2	11.0	13.9	11.2
0.5 ft. above MHW (Hours)	24	73	53	86	110	0	23	2	210	75	91	185	932
Frequency (# of events)	2	11	5	12	8	0	4	1	21	13	13	22	112
% of month	3.2	10.9	7.1	11.9	14.8		3.2	0.26	29.2	10.0	12.6	24.9	10.6
Mean time/event (hr)	12	6.6	10.6	7.2	13.8		5.8	2	10	5.8	7.0	8.4	8.3

when salinities are generally high and circulation from the gulf predominates, and December, when strong wind patterns and precipitation events flush the marsh with water that varies in origin between riverine and marine.

SALINITY

Spatial Variation

Monthly mean surface salinities were computed from selected Louisiana Wildlife and Fisheries biological and hydrologic sampling stations (Fig. 16) in the Vermilion-Atchafalaya complex (Juneau et al. 1975). The station with the lowest mean salinity record for the two-year period was number 17, where the Intracoastal Waterway (IWW) intersects with the Boston Canal (Fig. 16), while the station with the highest mean salinity record was the Fresh Water Bayou station (15). These stations exhibit salinity profiles that differ from location to location (Fig. 16, insets). Stations at the IWW at Boston Canal (17), Vermilion Bay (13), Blue Point (7), and Dry Reef (10) show a minimum salinity in May and a maximum in August. The station at Pelican Point (6), lags this pattern by one month with the minimum salinity recorded for June and the maximum in September. This pattern is possibly caused by a reflecting lag in circulation of both the freshet and the high salinity water into this section of the bay. The Fearman Bayou (14) station exhibits a longer low salinity period; the bayou drains the marsh area into the western shore of Vermilion Bay. The Lighthouse Point (12), Southwest Pass (11), and Fresh Water Bayou (15) stations exhibit markedly different patterns from the embayed stations. Although protected within a tidal pass, the Southwest Point (11) station shows a higher mean value than does

Lighthouse Point (12) which is located on the gulf side of the pass. Southwest Pass shows a minimum salinity for March and a maximum in July. However, Lighthouse Point (12) and Fresh Water Bayou (15) reveal anomalous patterns. The station at Vermilion River Cutoff (13) exhibits fluctuations in the spring and records a minimum salinity by June, a primary maximum in August, a second minimum in September, and a maximum in November with a decrease in value in December. The Fresh Water Bayou (15) station displays a minimum in May, a maximum in July, and lowering again in November. This is undoubtedly related to the pulses of freshwater discharge from the Atchafalaya River. Because one of the sampling years was 1973, it can be assumed that the primary spring minimum (March and April) salinity at these two stations results from above-named flood water from the Atchafalaya River for this year; Station 12 appears to show the effects of fresher water for a longer period of time. Surplus water for the Vermilion River demonstrates that 1973 was an extreme year when compared to the long-term surplus record. The fall of 1973 was also wetter than usual with large surpluses occurring during September (Fig. 17). This accounts for the very low salinities both offshore and within the Vermilion embayment for this year.

Seasonal Cycles

Long term (1947-1974) mean monthly salinities expressed as chlorides (ppt) were computed for the Vermilion Lock station (Fig. 18). The salinity station is located on the impounded side of the lock. Thus these salinities are dependent upon lock operation. In general the seasonal cycle at this station is similar to that of salinity cycles at other less impacted stations. These stations show that salinities are low in the spring and increase through November and decrease again in December.

The standard deviation of monthly salinity (chlorides) follows a pattern similar to mean monthly salinity, however, it should be noted that standard deviations are very large, even exceeding the mean salinity value.

Long-Term Trends

Long-term trends of mean salinity values follow the typical seasonal pattern, however, the reliability of the estimates is low. Analysis revealed that for 95 percent of the time the mean chloride concentrations at Vermilion Lock during September were within the range 1.0 ppt $\pm$ 2.8 ppt. Thus, the standard deviation is not normally distributed but depends on the mean value. There is more variability when mean values are highest in late summer and fall. Mean annual salinity for Vermilion Lock was plotted (Fig. 19) and a linear regression was performed on the annual mean salinity as a function of time. A highly significant trend was noted; chloride concentration behind the Vermilion Lock is decreasing at an average rate of 29 mg Cl^-/liter/year. This regression of chloride concentration through time accounted for 18 percent of the total variation. Thus, there is a great deal of variation unaccounted for in the long term trend analysis. As seen in Figure 19, any individual year may not experience a decrease in chloride concentration from the previous year.

If salinities are reduced by impoundment procedures circulation is also reduced. And it is possible that with a reduction flushing, nutrient transport to estuaries may be modified significantly, especially during times of continuous lock closure.

PRECIS OF WATER MANAGEMENT PRACTICES

Description and Operational Procedures

Lock operation records have been kept on a number of lock systems in coastal Louisiana by the New Orleans District, Army Engineers (CE). Among the projects is the Mermentau River, La., Project Area in which the following locks as control structures are located: Vermilion Lock, Schooner Bayou Control Structure (Fig. 20), Calcasieu Lock, and Catfish Point Control Structure. Although this overlaps on three basin management units, Calcasieu, Mermentau, and Vermilion, they are considered as part of one water level management area. The locks peripheral to the Mermentau Basin impede water flow through the waterways and thus keep water levels high within the Basin. Water levels can only be managed when there is an excess of fresh water within the Basin. If there is a deficit of fresh water in the Basin, salinities are raised. During some years locking has been restricted or discontinued altogether because water levels were too low for navigation and they would or could not admit gulf waters to raise them.

In general, when precipitation is below normal in the Basin water levels will not respond to tidal influence because locks will be closed. In the winter and fall when there is much precipitation locks stay open for long periods if there is sufficient load, or are opened only during a falling tide to drain off excess fresh water.

When a precipitation event occurs over an area including Calcasieu Lock, Lafayette, Mermentau, Oakdale, Opelousas, Vermilion Lock, and Catfish Point, the locks are usually opened two to four days later indicating that the first drainage from runoff has a 48-96 hour coastwise lag to the gaging stations in the marsh; total drainage time may range up to two months.

Locks are usually closed from June through October. This is the time of lowest water levels, and precipitation runoff is held in the Basin to maintain the minimum level. However, if there is a large excess of fresh water and minimum levels are exceeded, locks may be left open totally or partially for the entire summer.

If water levels fall below 0.5 feet above MSL, then locking is restricted totally to prevent massive intrusions of salt water.

Categories of lock control practices and guidelines for operation include the following:

- Closed. If a lock or control structure is closed for the entire day for water level control, it is classified as closed. This does not include openings for navigation.
- Open or Partially Open. If a lock or control structure is open all day it is classified as open; anything less is considered partially open. This can be as short as 10 or 20 minutes and still be classified as a partial opening.
- Restricted. If water levels are extremely high or extremely low, locking may be restricted due to dangerous conditions or to avoid excessive influx of salt water.
- Discontinued. If water levels become extremely high or extremely low, locking may be discontinued altogether to prevent dangerous conditions due to channel shoaling and/or excessive influx of saline water.
- Bypass Channel Open. At times when repairs need to be made to a lock or after traffic accidents to the lock, locking may be suspended

and an earthen dam adjacent to the lock dynamited to allow traffic to use a bypass channel. At this time salt water flows into the basin unobstructed.

The following description of individual control structures provides historical documentation of lock implacement and details of lock operation procedures and objectives. Refer to Figure 1 for locations and relationship to basin hydrology.

Fresh Water Bayou Lock

The Fresh Water Bayou, La., navigation project was authorized by Public Law 86-64S, approved July 14, 1960. The work was completed August 26, 1968.

This project provided for a lock, approach channels, tie-in levees, and a reservation area. The lock chamber is 84 feet wide and has a usable length of 600 feet. The floor and sills are at an elevation of 16.78 feet below mean sea level. The structure consists essentially of two concrete "U frame" gate bays with sector gates connected by an earth chamber with riprapped bottom and slide slopes. For dewatering purposes the gate bays have slots for single span needle beams and concrete needles. Lock gates consist of two structural steel 70-degree sector leaves, each individually operated by an electro-hydraulic system. Normal lock operation for navigation consists of equalizing the chamber water level with either the gulf stage or the canal stage. This is affected by opening the appropriate gate, admitting the vessel, closing the gate, equalizing the chamber water level to the opposite water stage by opening the opposite gate, then permitting the vessel to leave the lock.

Abnormal operation of the lock is provided for in the event of: abnormal tides, winds, hurricanes, and times when it is necessary to flush saline water from within the canal.

- Abnormal tide: Beef Ridge, through which the lock is constructed, forms a natural barrier against storm tides whose heights change up to 4 or 5 feet above MSL. When storm tides rise above this ridge, the entire land area around and north of the lock floods. It is estimated that the water surface elevations will essentially be equalized on both sides of the lock when tide elevation extends 6.8 feet above MSL. At this point the landside gate becomes ineffective; the gate then is operated until the storm tides reach 6.8 feet, and then left open, except during lockages. The gulfside gate is operated until the storm tides reach 9.8 feet above MSL, and then closed to prevent rapid flow of water through the earth chamber. Operations are discontinued until storm tide stages have receded to 6.8 feet.
- Abnormal winds. Irrespective of the conditions cited above, vessels will be locked through until the wind velocity reaches the point that locking becomes hazardous to facility personnel and to the lock. At this point, both gates will be kept closed.
- During hurricanes and when warning are posted, all structures and gates are closed and lock personnel should evacuate the premises.
- To flush saline water from the canals and the landside channel may require at infrequent intervals opening the lock. On these occasions, the lock will be operated in accordance with the instructions of the District Engineer.

Schooner Bayou Lock

Schooner Bayou Lock and Dam was authorized under allotments from the appropriation provided by section 6 of the river and harbor act of March 3, 1909. The Schooner Bayou Lock was completed in 1913 and the dam was completed in 1914. The lock was designed as a water control system along the Intracoastal Waterway that connected White Lake and Vermilion Bay. In 1951 the lock and dam was abandoned and relocated in its present position (Fig. 20). The abandoned section of the waterway was leveed off. This segment of the Schooner Bayou Control Structure was completed on May 22, 1951, and it functions as the primary water control facility along the IWW between White Lake and Vermilion Bay. The Control Structure consists of two 75-foot gate bays, each equipped with a pair of 60-degree steel sector gates. The sill elevation of both gates is set at 12.78 feet below MSL. Each sector gate may be independently operated from either local or remote control switches. The structure is protected on the flanks from overbank flow by earth dikes constructed on both sides of the structure.

Vermilion Lock

Vermilion Lock was authorized by the River and Harbor Act of March 3, 1925, to be a feature of the Gulf Intracoastal Waterway. This lock is located two miles west of Intracoastal City, La., and 18 miles southwest of Abbeville, La. This lock was initiated in 1932, opened for navigation in 1933, and completed in 1934. Plans were approved by the Secretary of the Army on May 6, 1976, to replace the existing lock with a larger lock, thereby providing adequate facilities for both existing and projected navigation requirements. Construction could commence as early as FY 1978 provided Congressional approval is received in FY 1977.

The existing Vermilion Lock consists of two reinforced concrete gate bays with bottom hinged gates; the spillways that connect the gate bays to the north bank of the channel are reinforced concrete. Each spillway has five sluice gates eight feet wide and ten feet high. The lock is 56 feet wide and 1,182 feet long. The depth over the gates is 12.1 feet below MSL. The top elevation of the gate bays is 5.3 feet above MSL. Filling and emptying of the lock is accomplished by opening and closing the appropriate sluice gates.

The following rationale applies to the operation of Schooner Lock and Vermilion Lock:

> The regulation of freshwater outflow and saltwater inflow relative to the freshwater reservoir of the lower Mermentau River Basin presents a complex problem of water management. Requirements for rice irrigation, flood control navigation, fish and wildlife management, and drainage, are quite divergent and vary with the seasons and with hydrologic and meteorologic events. One or more interests could be adversely affected with varying degrees of severity, unless the needs of all were considered. Consequently, a flexible plan of regulation, based on current data and conditions, is deemed essential in order to obtain the maximum benefits to the project and to minimize and distribute losses equitably to interests concerned (Schooner Bayou and Vermilion Lock Operation and Maintenance Manual, n.d.).

Thus the operation of these locks must provide for the regulation of the freshwater reservoir in such a way as to provide for:

- conservation of fresh water by maintaining normal lake stages at 1.28 feet above mean sea level
- prevention of uncontrolled tidal inflow during the rice irrigating season April through August
- prompt and efficient release of flood waters during abnormal high water stages

- limitation of minimum stages to zero mean low gulf (0.78 feet below mean sea level) in view of navigation requirements
- the periodical operation of gates in the interest of fish and wildlife management when not detrimental to other major interests. Specifically gates will be opened to permit escape of flood flows when stages are above 1.28 feet MSL and nonmodifying conditions, as discussed below, prevail.

From December 1 through August 30, except as required for flood control, gates are operated to conserve fresh water and exclude salt water. This does not hold for rice irrigation season (April through August) when heavy withdrawals for irrigation exceed runoff and lake storage is being drawn upon. During the April-August period Schooner Bayou Control Structure is operated to draw water from Vermilion Bay to keep waterway and lake levels from falling below 0.78 feet below mean sea level. This schedule allows navigation and makes the maximum amount of fresh water available for irrigation. When the preceeding rules are in conflict, as they will be when stages are above 1.28 feet above MSL during certain periods of the year, all pertinent conditions including prior and forecast conditions will be considered and the gates will be operated to obtain optimum overall results.

From September 1 to November 30 gates will be operated as stage conditions require for the overall optimum benefit of flood control, navigation, exclusion of intruding salt water, and fish and wildlife production.

Figure 21 includes annual summaries of lock operation records for Vermilion Lock and Schooner Bayou Control Structure. Other information such as mean basin water levels (not reproduced here) indicate that water levels are maintained at about 1.42 feet above MSL. In the early fifties this practice did not require as much locking time as it did in the mid seventies. Almost the entire years of 1973, 74, and 75 required open locks to maintain water levels at 1.42 feet MSL.

East and West Calumet Floodgates

The East and West Calumet Floodgates were constructed under the "Flood Control, Mississippi River and Tributaries" project, authorized by the F lood Control Act of May 15, 1928.

The East and West Calumet Floodgates are located in the East and West Wax Lake Outlet guide levees at their intersection with Bayou Teche, in St. Mary Parish about 7 miles west of Patterson, La. The purposes of the floodgates are to provide a means of controlling the flow of fresh water from Wax Lake Outlet into Bayou Teche and to pass navigation through the guide levees.

The floodgate is a reinforced concrete structure of "U frame" design with a single set of steel sector gates. The floodgates are 45 feet wide and have sill elevations of 9.8 feet below MSL. The work on both floodgate structures was completed on March 14, 1950. The closure of Bayou Teche west of Wax Lake Outlet was completed March 20, 1950, and the approach channels for the West Calumet floodgate were completed July 12, 1950.

In general the floodgates are unattended. The lockmaster at Berwick Lock is responsible for operation and maintenance of the floodgates.

Operation

The gates are operated to allow navigation, to permit inflow of fresh water from Wax Lake Outlet, or to permit outflow of natural runoff from Bayou Teche into Wax Lake Outlet as follows:

- Operation of the floodgates for passage of navigation is in accordance with the navigation regulations contained in Section 207.180, 33 CFR. Anyone wishing to go through the floodgate shall notify the lockmaster of Berwick Lock at least 8 hours in advance. The lockmaster will provide an operator who will open and close the floodgates. When it becomes necessary to close the gates for prolonged periods, operating crews will be on duty 16 hours per day.
- Upon the request of responsible local officials and approval of the Chief, Operations Division, the gates will be open to permit the flow of fresh water from Wax Lake Outlet into the landside area.
- Operating procedures for both structures are as follows: West Calumet Floodgates. Gates remain fully open for outside (Wax Lake Outlet) stages under 3.0 feet MSL. When outside stages reach 3.0 feet above MSL and higher, the gates are closed except as necessary to pass navigation. Gates are operated for navigation until the differential head exceeds that allowed for safe operation of the structure. East Calumet Floodgates. Gates remain fully open for outside (Wax Lake Outlet) stages below 3.0 MSL. When outside stages reach 3.0 feet MSL and higher, the gates are closed except as necessary to pass navigation. East Calumet Floodgate is closed to navigation when the river gage at Berwick Lock reaches 3.0 feet above MSL and higher. When inside stages exceed outside stages and the pool on the inside is more than adequate for local use, then the gates are opened to relieve excess.
- In order to prevent excessive velocities and scour, the gates are opened according to the following schedule, except when passing navigation.

GATE OPENING SCHEDULE

Differential head in feet	Maximum allowable gate opening in feet
0.5	45
1.0	30
1.5	20
2.0	14
3.0	10
4.0	7
5.0	5
6.0	4
7.0	4

The differential head shall be determined from staff gages located a minimum of 200 feet from each floodgate.

- The maximum allowable gate openings are conservative, and should provide an adequate margin of safety for stage fluctuations while unattended for periods of 24 hours. The operator should, however, be alert for the development of an unsafe condition. In addition, occasional soundings should be made in the vicinity of the riprap to insure that excessive scour is not occurring. Gate openings in excess of those indicated in the opening schedule are permissible for short periods to pass navigation, provided that the operator considers that the passage can be made safely. But, at no time shall the gates be opened for navigation when the differential head across the gates exceeds 3 feet.

Ruth Canal

A rice conglomerate built the Ruth Canal in 1919 to drain water from Bayou Teche into the Vermilion River. This was to keep a sufficient water head on the Vermilion so that salt water would not intrude up the river's channel. Major modifications to the canal were completed in 1944. Ruth Canal greatly benefits the rice-growing community. The canal operates from March through July, closing the remainder of the year.

In summary, the following describes water management in Vermilion Basin:

- Calumet Floodgates permit excess Atchafalaya River flow to exit from the Lower Atchafalaya River and Wax Lake Outlet and pass through the Intracoastal Waterway and Charenton Drainage Canal.
- Ruth Canal and its associated water control structures permit diversion only from artificially high levels in Bayou Teche and maintain sufficient head on the Vermilion River so that salt water will not intrude up the river's channel.
- Fresh Water Bayou Control Structure maintains elevated water levels in the area east of White Lake and prevents salinity intrusion while maintaining a usable waterway.
- Schooner Bayou Control Structure and Vermilion Lock maintain elevated water levels in the White Lake/Grand Lake area and prevent salinity intrusion.

Water levels are maintained at elevated levels in the Mermentau Basin to facilitate pumping surface water from the Mermentau River. Although White Lake is not pumped, it acts to store fresh water and maintain an effective barrier against salinity intrusion up major channels to the pumping stations. Irrigation water is pumped from Grand Lake and if water levels are not maintained, the wind can blow the water to the extreme south end of the system and make it unavailable for irrigation.

These control structures are not effective against severe tropical storms, as wind-driven waves cause elevated water levels which frequently top the gates.

Environmental Response

The specific purpose of Vermilion Lock and Schooner Bayou Control

Structure is the maintenance of a large reserve of fresh water in the Mermentau Basin for rice irrigation. While the area impounded by these structures is not in the Vermilion Management Unit, this catchment would be an integral part of the Basin's estuary if there were no control structures. These structures regulate the natural intrusion of salt water from Vermilion Bay into the adjacent White Lake catchment basin from April through October.

Vermilion Lock and Schooner Bayou Control Structure work together to control freshwater runoff and maintain Mermentau Basin water levels at 1.4 feet above MSL. However, the locks are operated independently to allow navigation.

Records for 1954, 1956, and 1963 were chosen to illustrate environmental response to control structures. These periods represent abnormally low precipitation either for the entire year or for significant periods within the year.

The example of these years illustrate that management of impounded waters can only be successful if there is an excess of fresh water within a basin.

Figure 19, long-term salinity trends at Vermilion Lock, is a plot of mean annual salinity from 1947 to 1974. Two extreme salinity values show up in 1954 and 1956. These salinity levels were recorded on the west side of the lock, representing gulf water that penetrated the barrier. No salinity data is available at other stations further inland; the extent of salinity intrusion is unknown.

Both 1954 and 1956 were years of below-normal precipitation. In contrast, 1963--also of below-normal precipitation--shows no extreme salinity peak.

The interrelationships of these patterns were understood by studying unpublished records of the USACE, New Orleans District, on lock operations from 1951 to 1977. Included on these records are basin water levels, station water levels, basin precipitation, and locking procedures.

The records show that precipitation for January through March 1954 was abnormally low; 1956 and 1963 did not show extremely low precipitation at this period, but there was a deficit at the end of the period. April through August were very dry in 1963, but only moderately so in 1954 and 1956. September through December showed surpluses for 1963, but none for 1954 and 1956.

For the entire year, 1954 started off dry and remained dry; 1956 started off normal and became dry the rest of the year; 1963 was normal except for a dry April through September. Salinities were high in 1954 and 1956 and low for 1963. Both the Atchafalaya and Mississippi river discharges were low for the example years and therefore not responsible for the salinity value differences. The tabulation below shows river discharge in cubic feet per second (cfs) (Juneau 1975).

	Atchafalaya	Mississippi	Total
1954	94,000	262,000	356,000
1956	131,000	332,000	463,000
1963	110,000	268,000	378,000

During the period of freshwater deficit, water levels dropped below MSL within the Mermentau Basin area for all three years; however, only during 1963 was locking restricted at Vermilion Lock and discontinued at Schooner Bayou. Whether or not these measures were taken to prevent navigation from shoal areas or to prevent saltwater intrusion, the result was that salt water was kept out of the White Lake impoundment.

These kinds of problems may not be as much of a hazard in the mid to late seventies, unless drought conditions are severe. With increased Atchafalaya River discharge the entire Vermilion/Cote Blanche system is becoming fresher and there is less chance of massive saltwater intrusion into the management units behind the locks, except during severe tropical storms.

SUMMARY

The Vermilion Basin Management Unit is a dynamic, highly impacted basin. With massive influx of Atchafalaya River water from the east and tidal influence through both Southwest Pass and Cote Blanche Bay, a complex system of circulation results. The Basin boundaries are controlled by the Atchafalaya Basin guide levees on the east and the Fresh Water Bayou Project Levees, Schooner Bayou Control Structure, and Vermilion Lock on the west. This Basin is commercially important in terms of its waterways, commercial and sports fisheries, and vast source of fresh water for rice irrigation.

Locks and dams are located on all major waterways in the Vermilion Basin; these structures were constructed primarily for artificial maintenance of high water levels to aid rice farming. Water levels in impounded areas can only be maintained if there is an excess of fresh water. If deficits occur, saltwater intrusion becomes a problem. However, effective locking procedures preclude the likelihood of substantial saltwater intrusion.

The drainage area of the Vermilion Basin is small, comprised of minor streams peripheral to the Atchafalaya Basin system. Poor water-storage capabilities characterize the watershed with river discharge peaking unpredictably in response to precipitation. The Vermilion River shunts local drainage to the gulf, aided by its high banks in upland areas.

Tidal input through Southwest Pass enters Vermilion Bay. and. at times, extends up the Vermilion River as far as Lafayette. Vermilion Bay tides lead those at Bayou Rigaud by about five hours. Although mean montly tide ranges do not show much variation, there are considerable differences within the two-week cycle. Climatologic factors contribute to variations in tides and water levels. Winter storms associated with cold fronts set up circulation patterns in coastal areas and contribute to estuarine flushing. Information on long-term trends in tide range indicates that the range has been increasing, with the maximum value occurring in 1971. Projection of this cycle suggests gradual decline with a minimum occurring in 1980.

Water levels change slowly in Vermilion Bay due to its limited access to the gulf through a restricted tidal pass and the locks that limit the area of the Basin. At the same time that water levels are controlled, nutrient exchange is reduced to times when locks are open. Flushing of the marsh in the impounded area is restricted because lock operations are coordinated to correspond to falling tides, allowing exit of fresh water from the area. Salinity does intrude areas behind the locks, especially during times of low precipitation. Thus, although Vermilion Bay is a well-mixed estuarine system, the outlying marshes are fresh.

Vermilion Basin will not remain as it is today. With accelerated growth of the Atchafalaya Delta will come freshwater influx and increased suspended sediment supply. A change in the system is inevitable.

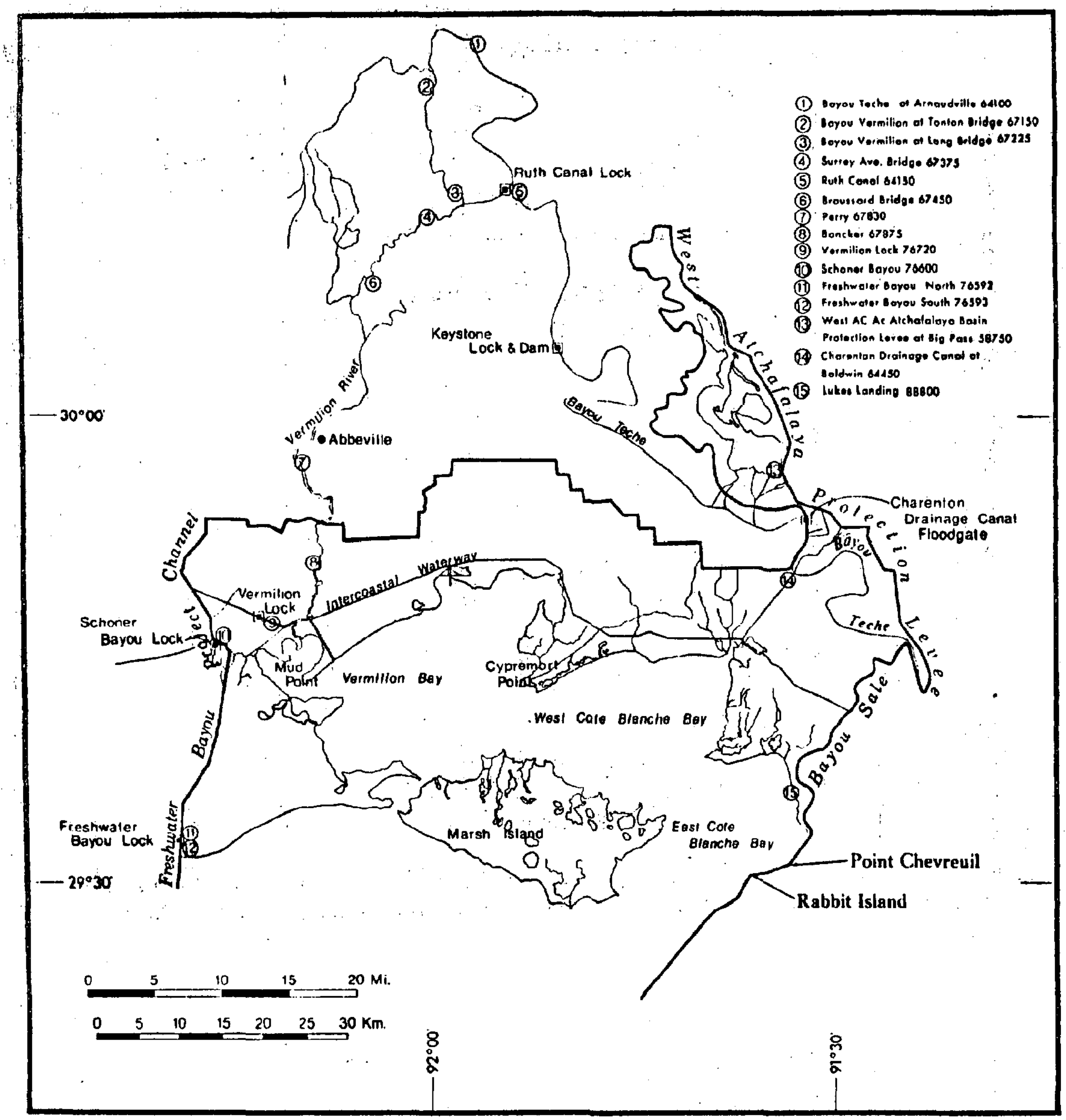


Fig. 1. Vermilion River drainage basin with locations of locks, dams, and gaging stations.

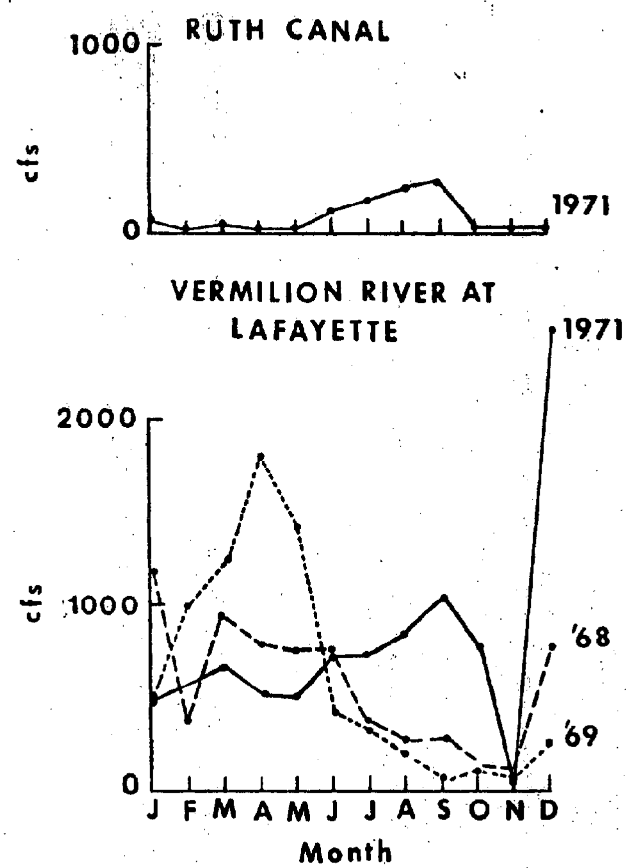


Fig. 2. Monthly mean river discharge for Vermilion River at Lafayette for 1968, 1969, and 1971 and monthly mean discharge for Ruth Canal @ Ruth for 1971.

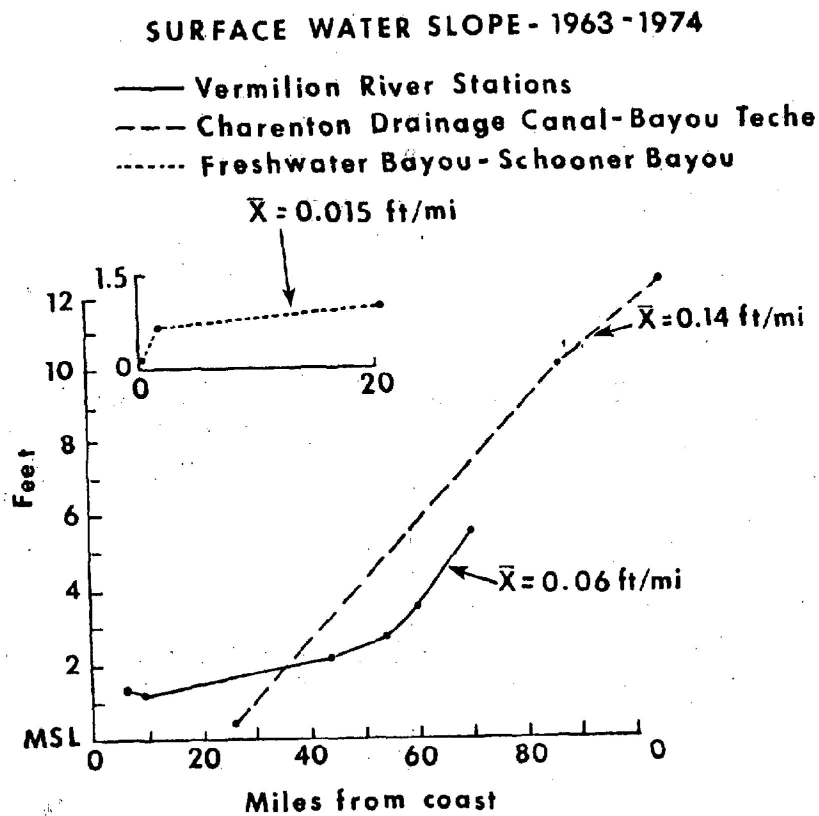


Fig. 3. Surface water slope for the three principal drainage systems in the Vermilion Basin.

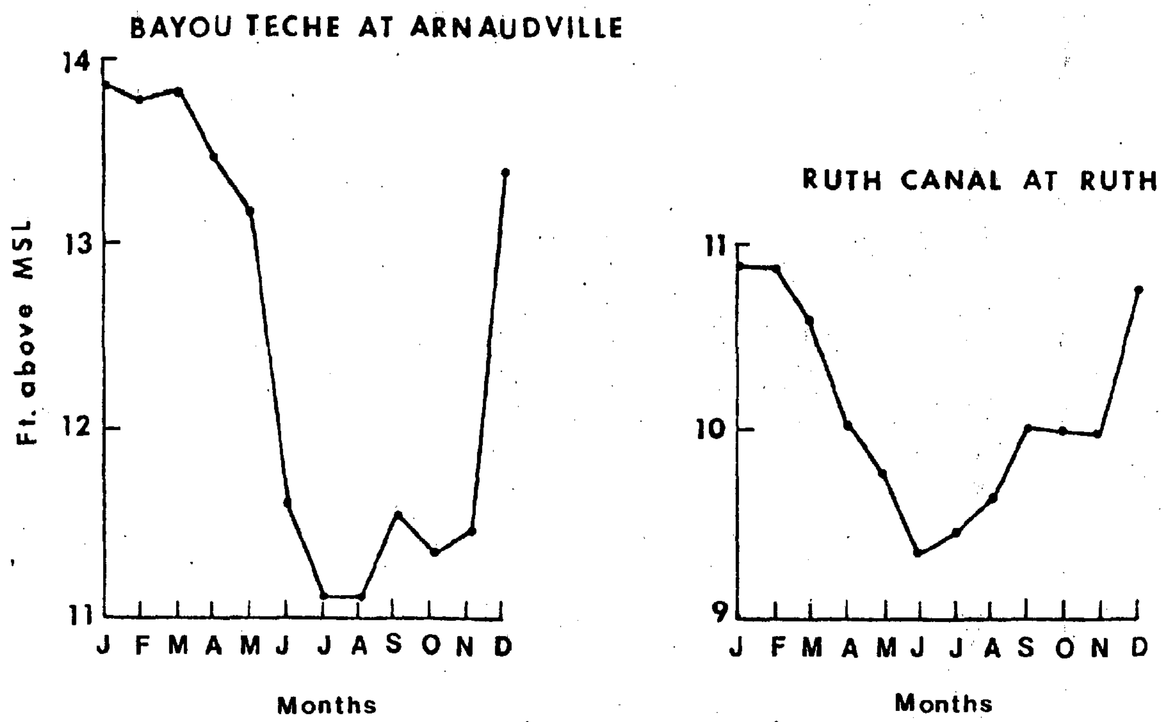


Fig. 4. Monthly mean water stage - Bayou Teche at Arnaudville and Ruth Canal at Ruth.

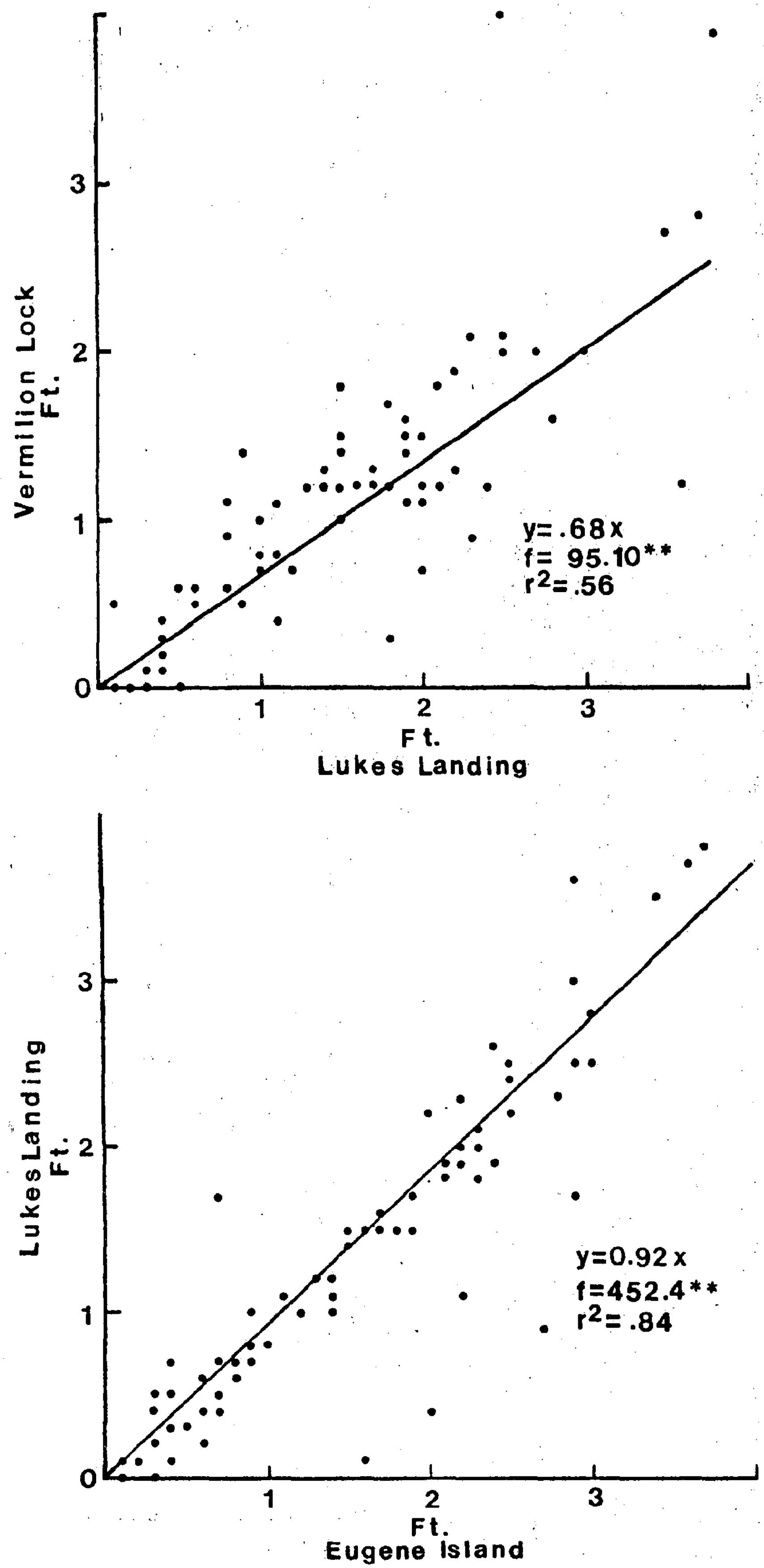


Fig. 5. Linear regression model for concurrent tide range pairs, Eugene Island-Luke's Landing and Luke's Landing-Vermilion Lock.

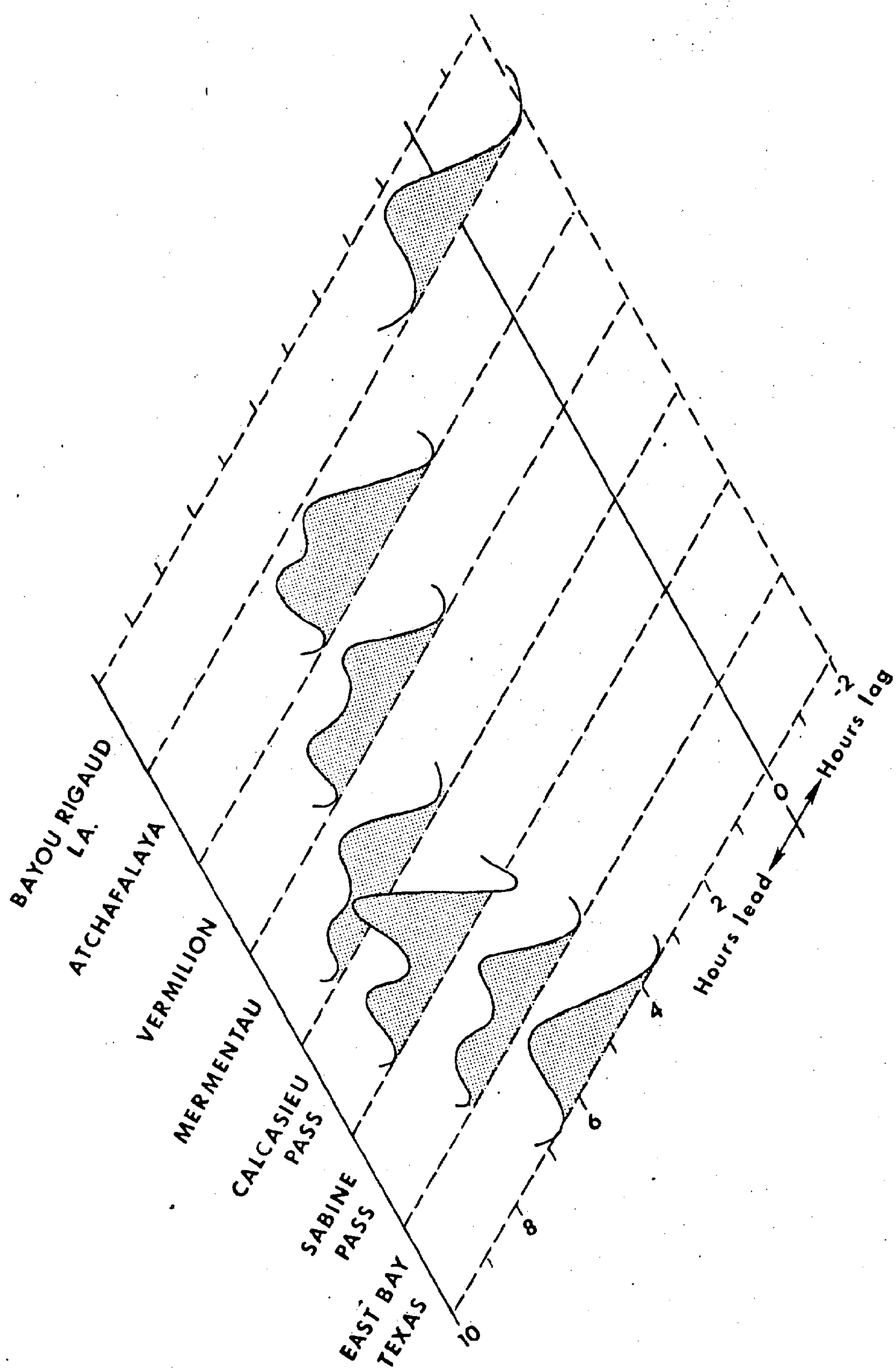


Fig. 7. Tide phase comparison for Louisiana and East Texas coast.

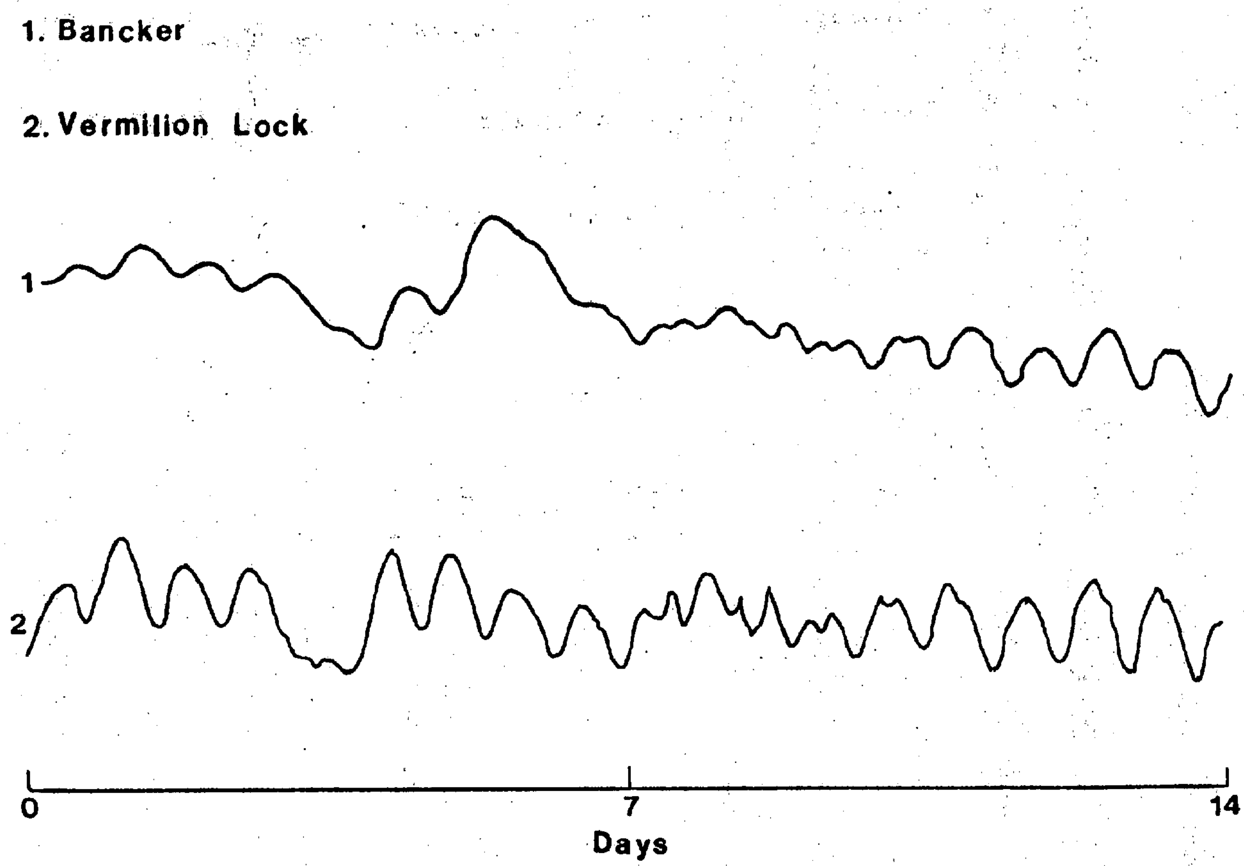


Fig. 8. Fortnightly tide pattern, Vermilion River at Vermilion Lock and Bancker.

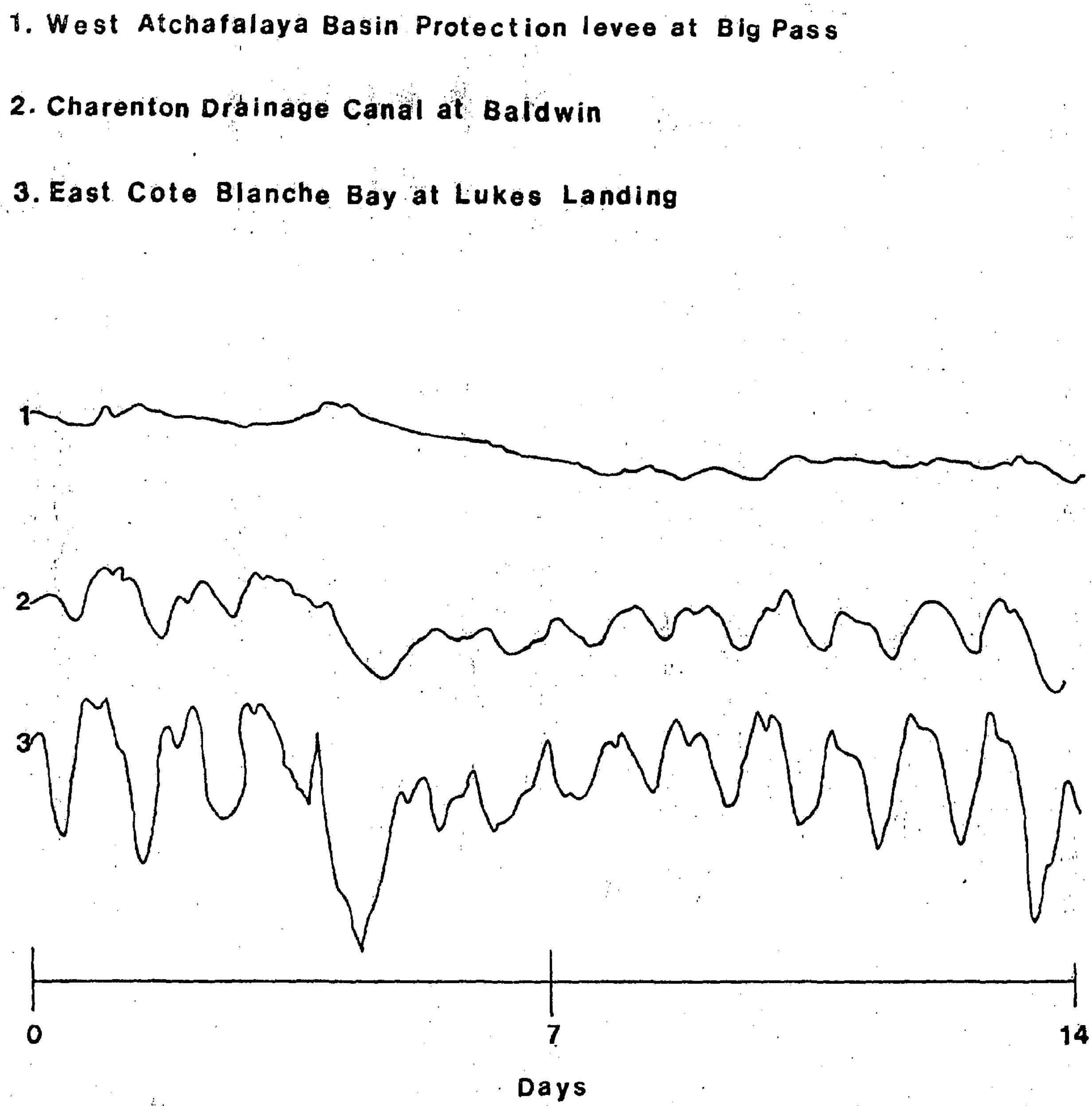


Fig. 9. Fortnightly tide pattern East Cote Blanche Bay at Luke's Landing, Charenton Drainage Canal at Baldwin, and WABPL Borrow Pit at Big Pass.

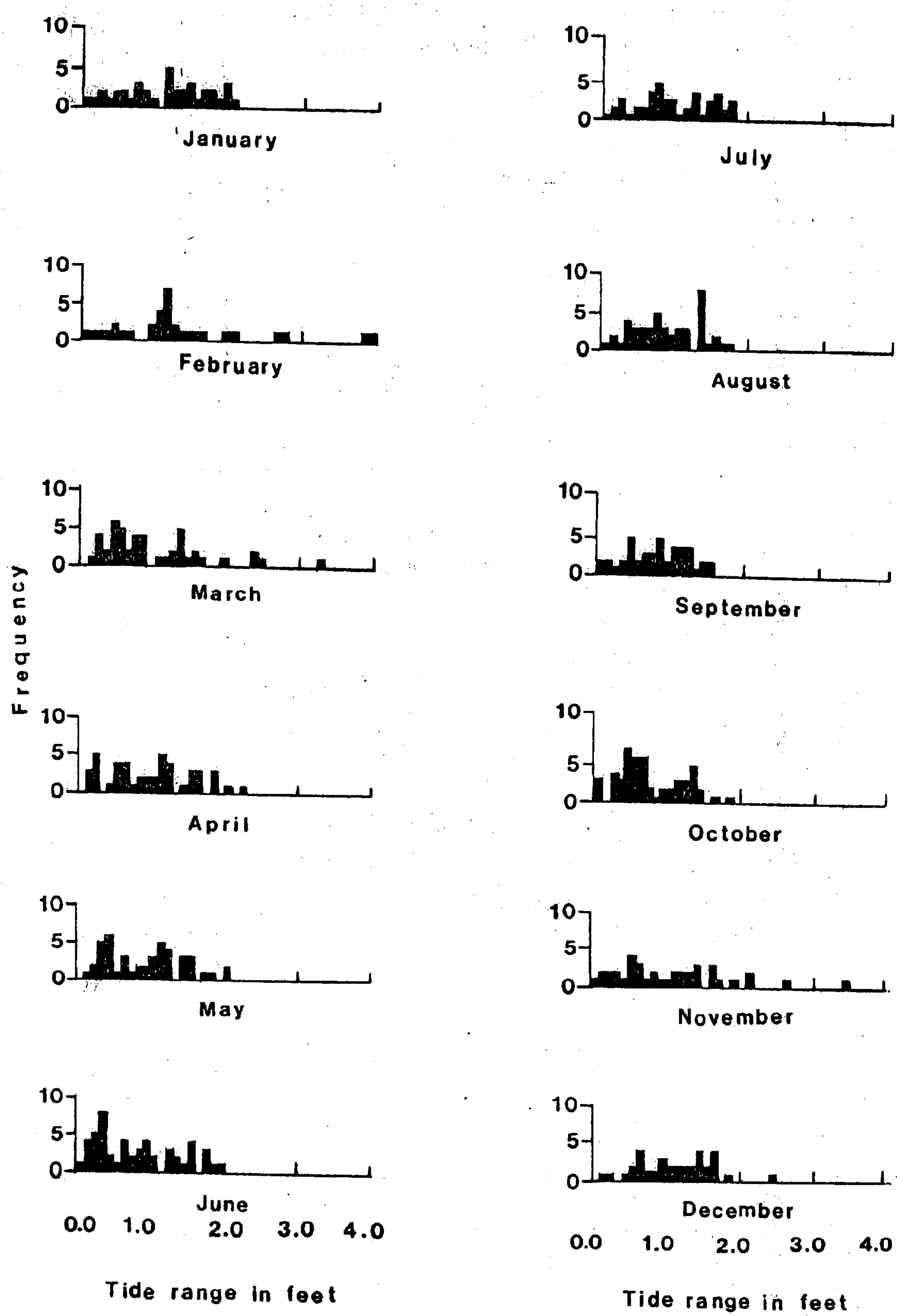


Fig. 10. Frequency-range relationships by month, Vermilion Lock, 1971.

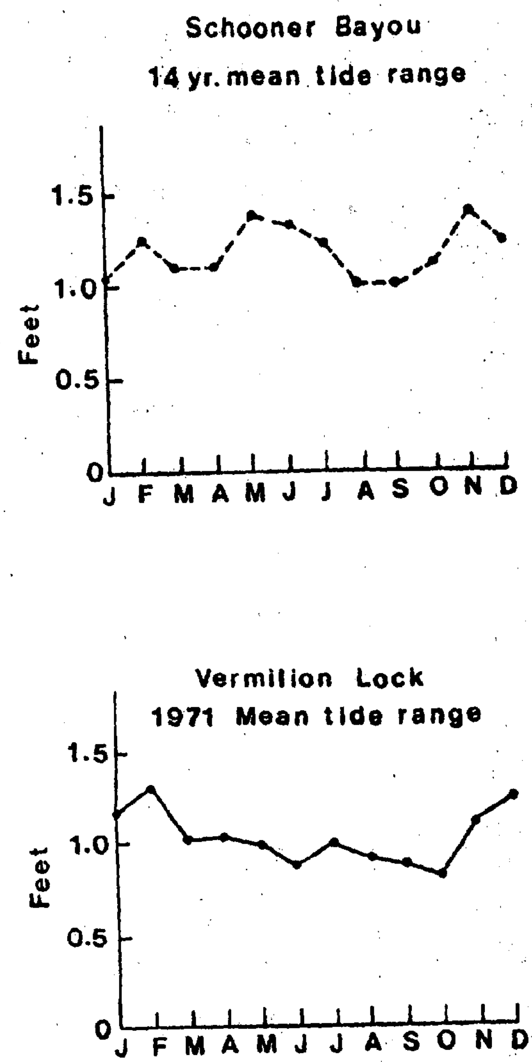


Fig. 11. Long term monthly mean tide range at Schooner Bayou and 1971 mean monthly tide range at Vermilion Lock.

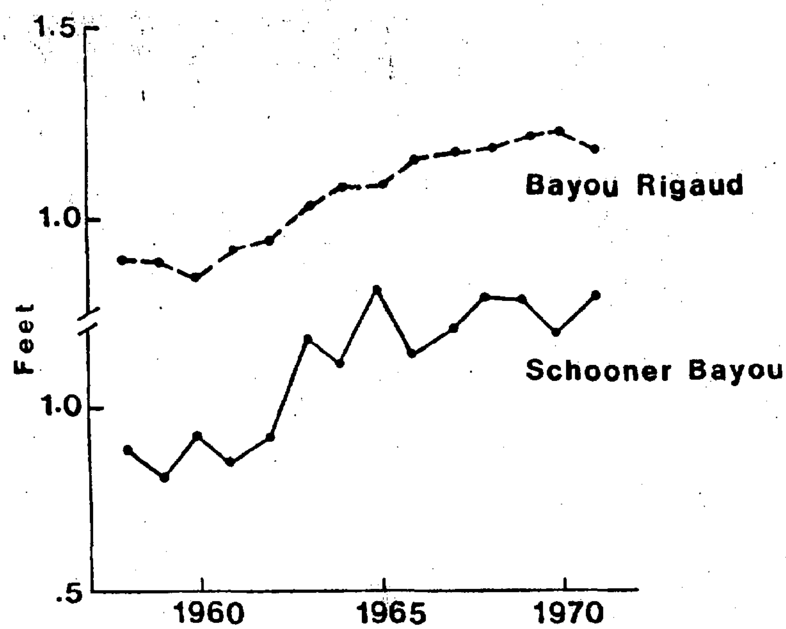


Fig. 12. Long term trends in tide range for Bayou Rigaud and Schooner Bayou.

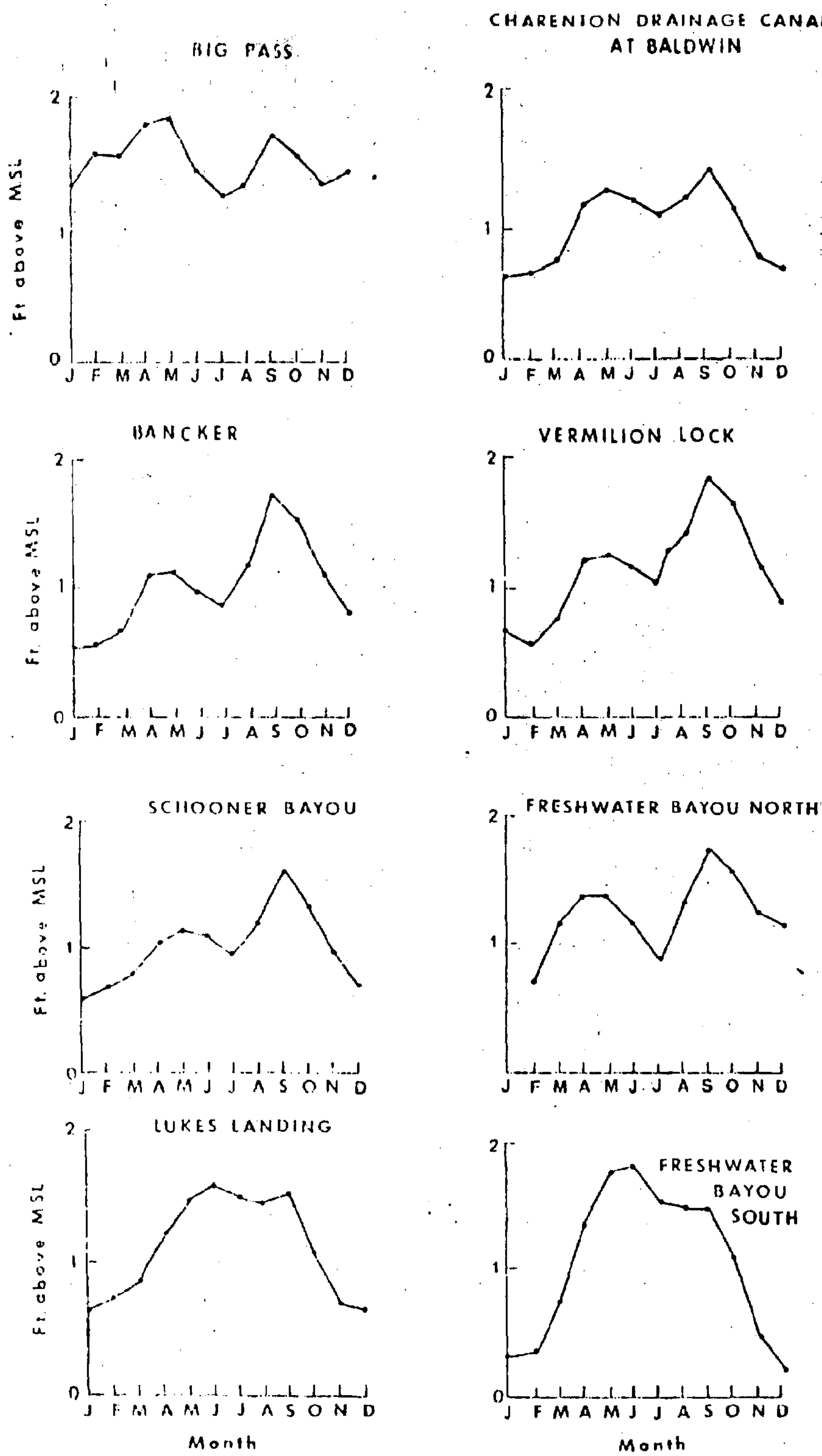


Fig. 13. Mean monthly water stage for tidally influenced gaging stations, Vermilion Basin, 1963-1974.

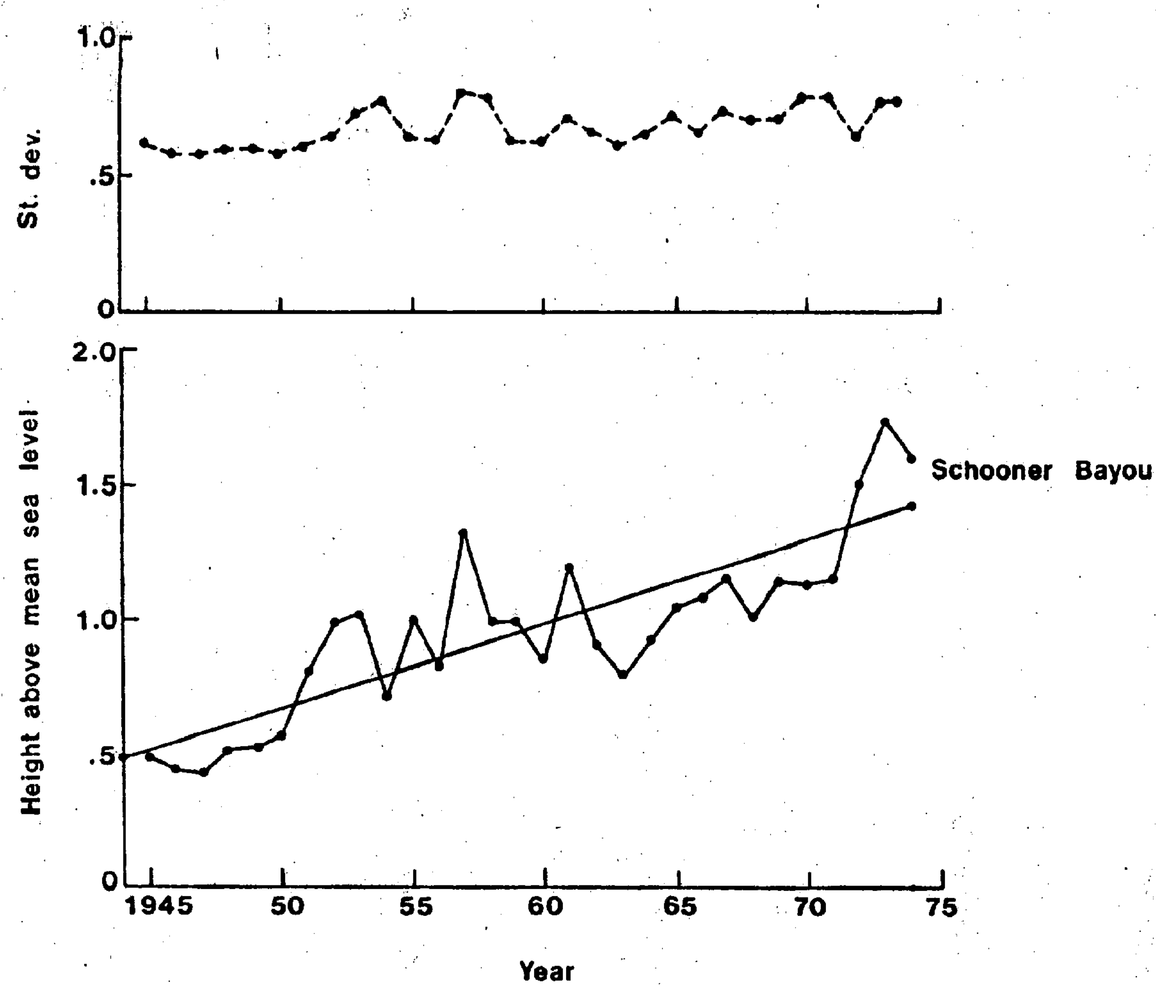


Fig. 14. Long term apparent water level trends for Schooner Bayou.

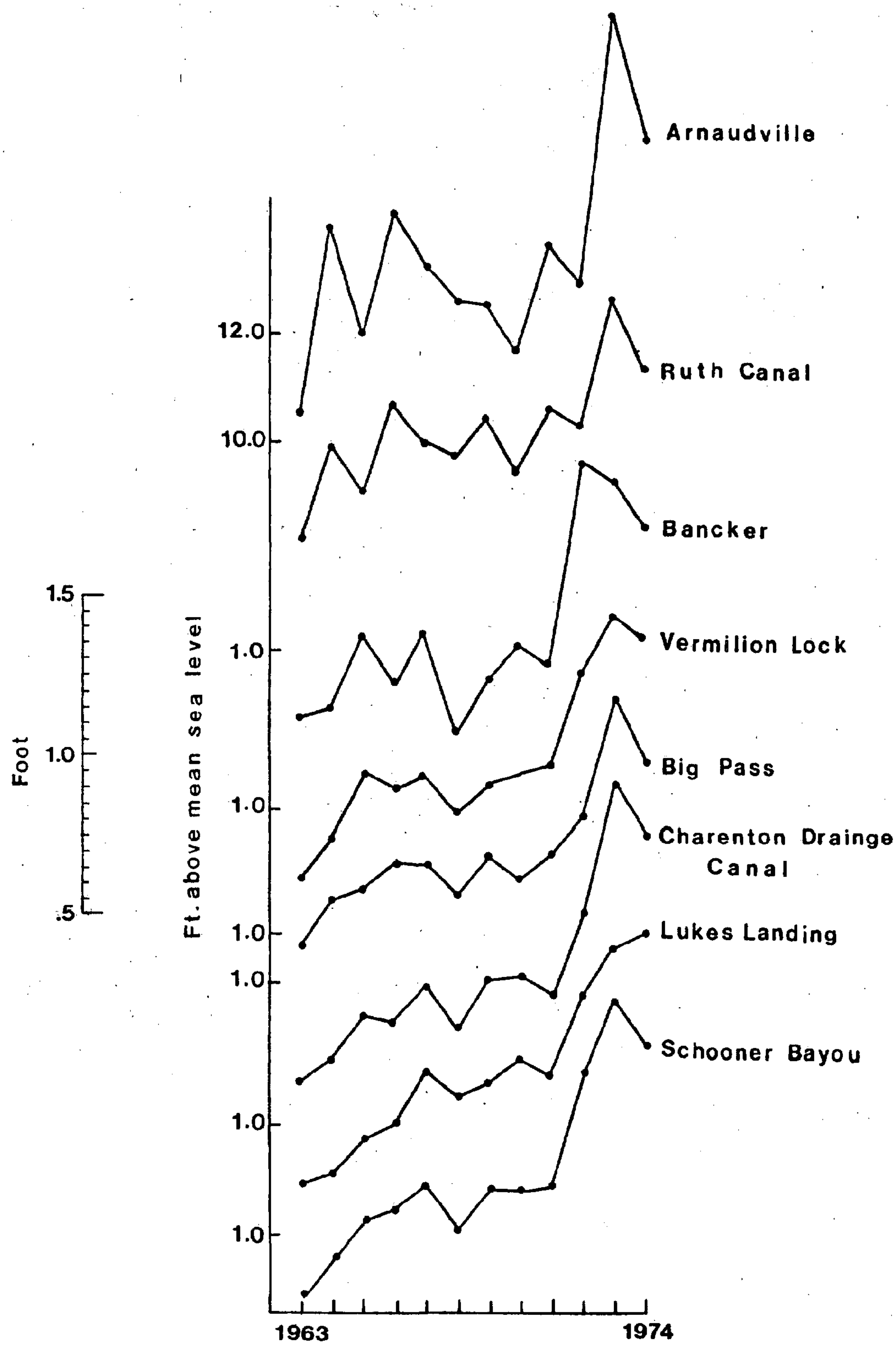


Fig. 15. Apparent water level trends - Vermilion Basin.

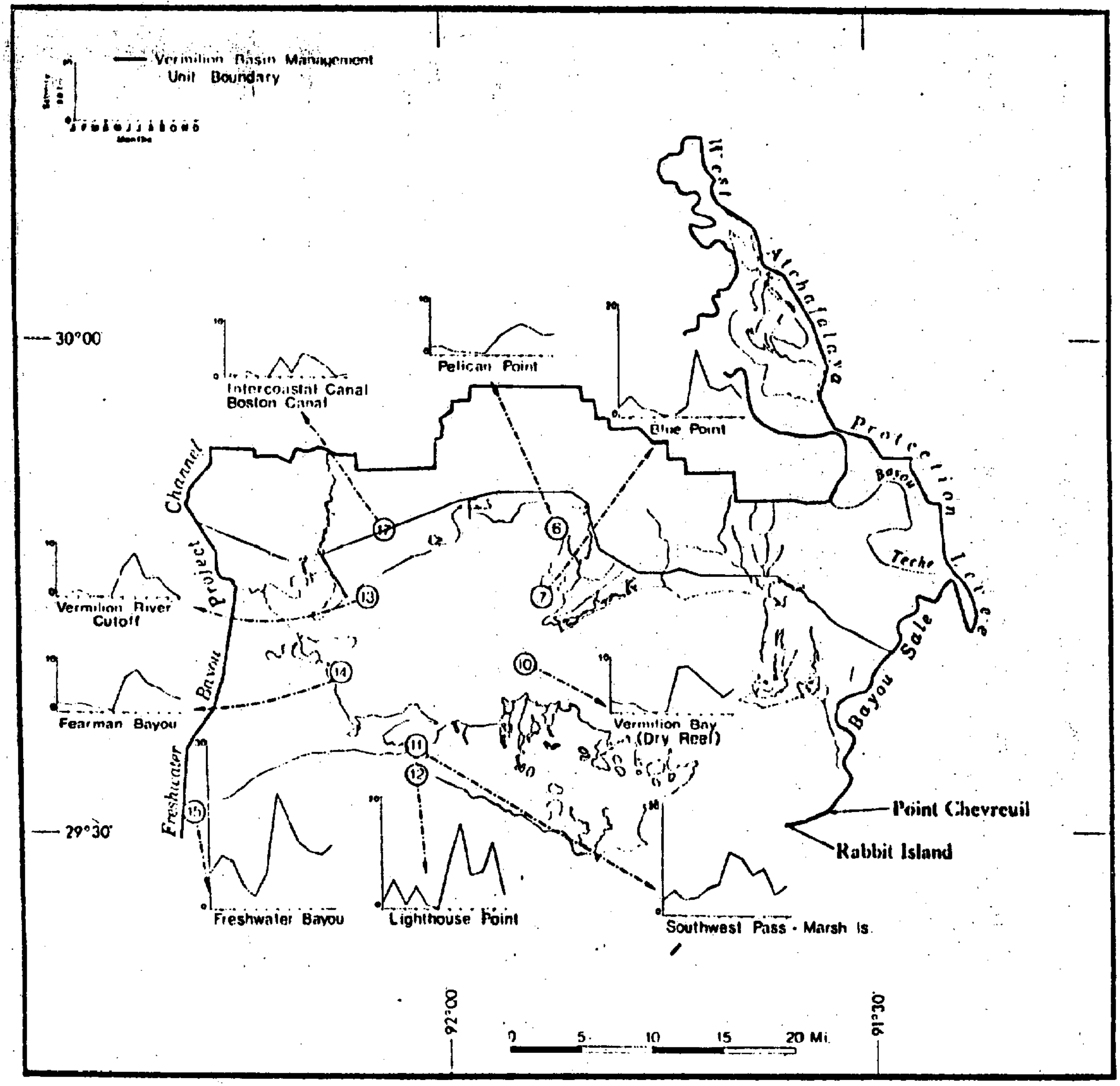


Fig. 16. Mean monthly salinity for 1971-1972 at selected stations, Vermilion Bay (Data from Juneau, 1975).

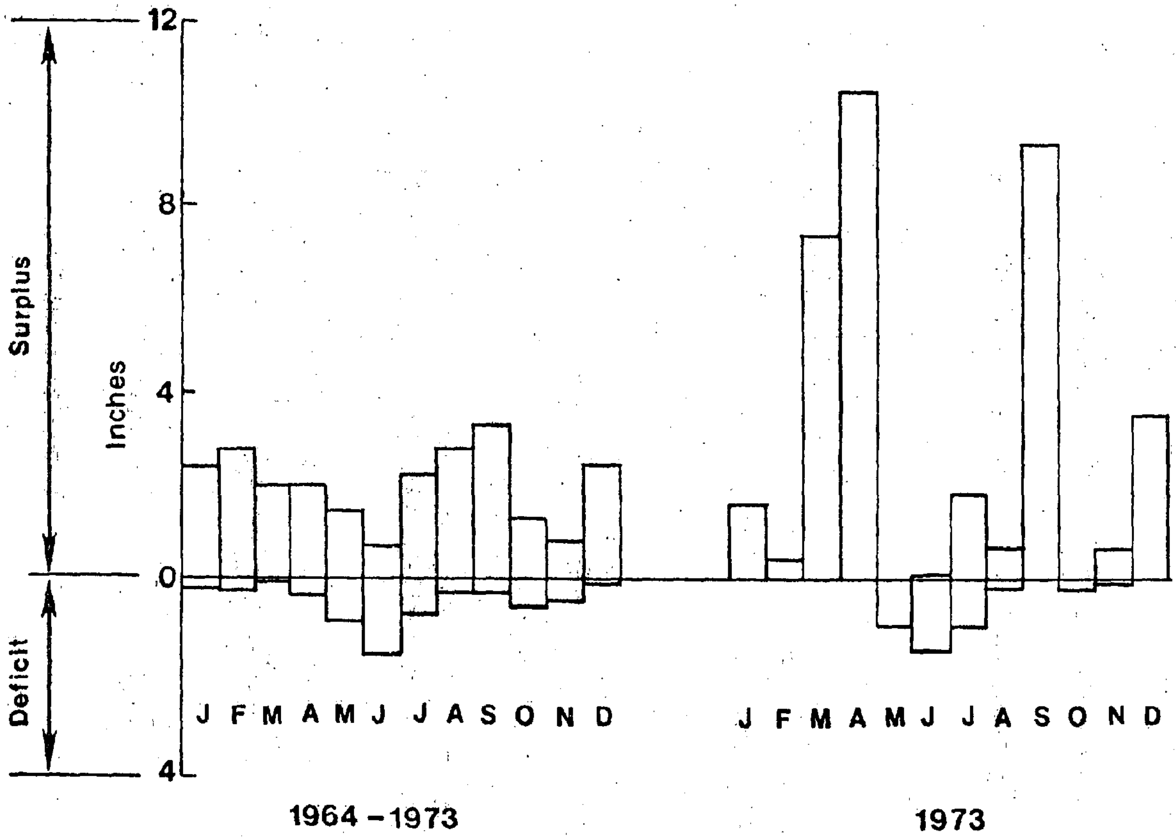


Fig. 17. Water budget - Vermilion Basin - 1964-1973 averaged and 1973.

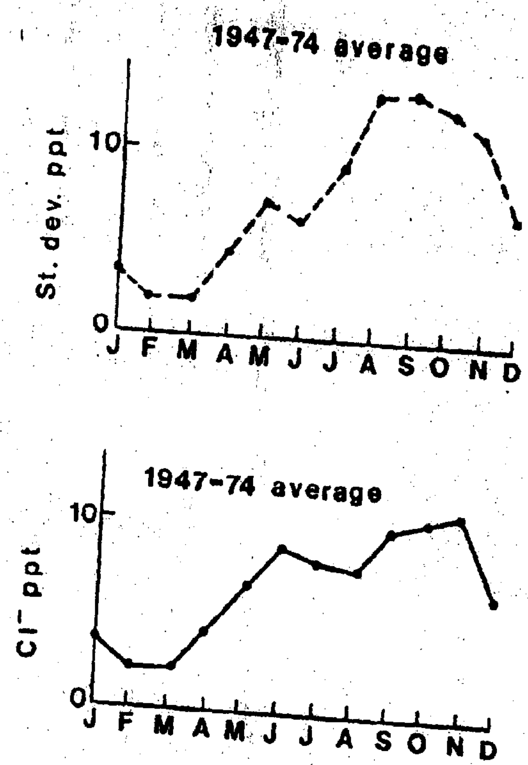


Fig. 18. Monthly mean salinity (Cl^-) and standard deviation, a measure of variability for Vermilion Lock 1947-1974.

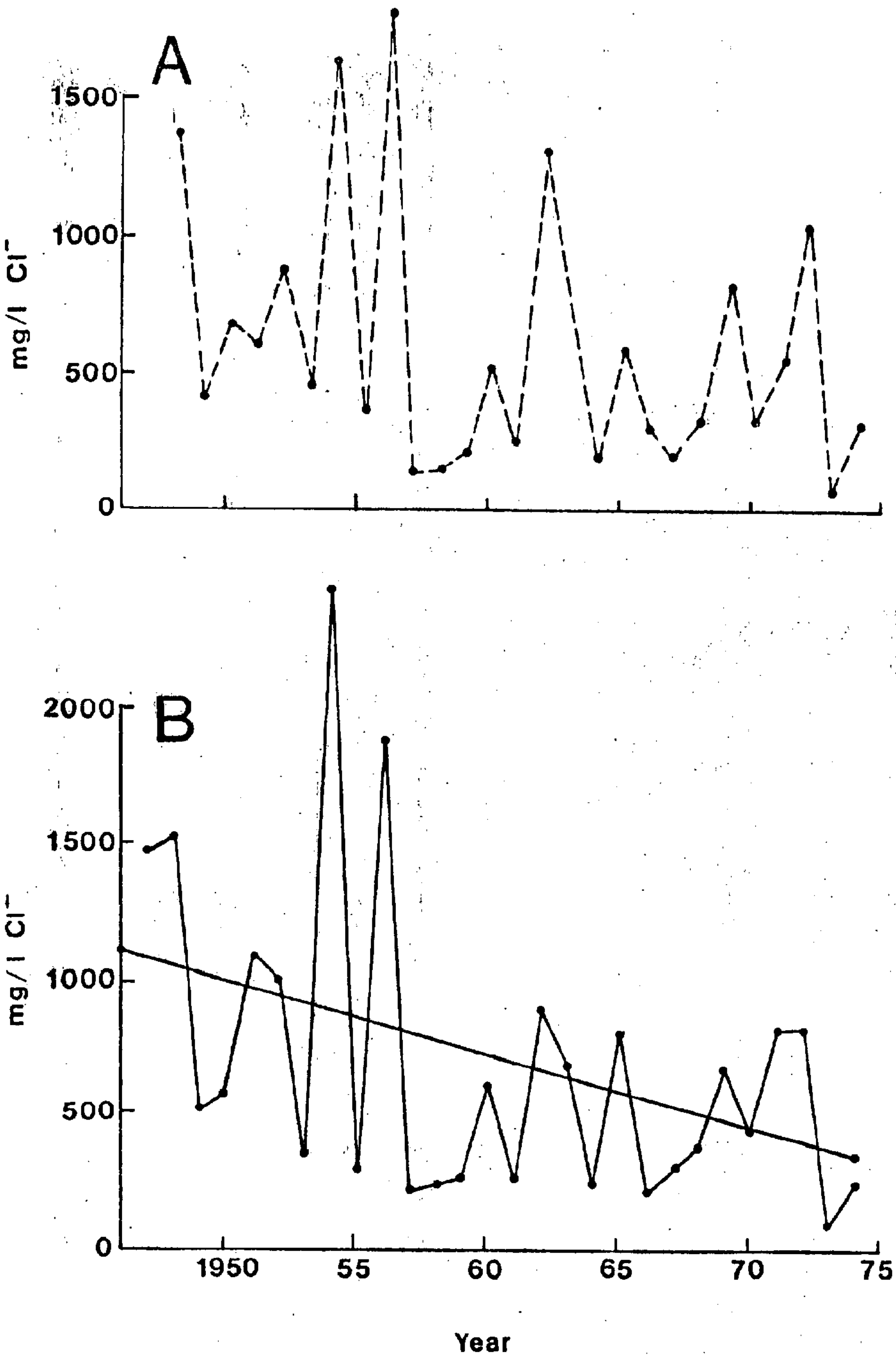


Fig. 19. Long term trends in salinity (mg·Cl^-/1) and standard deviation 1947–1974.

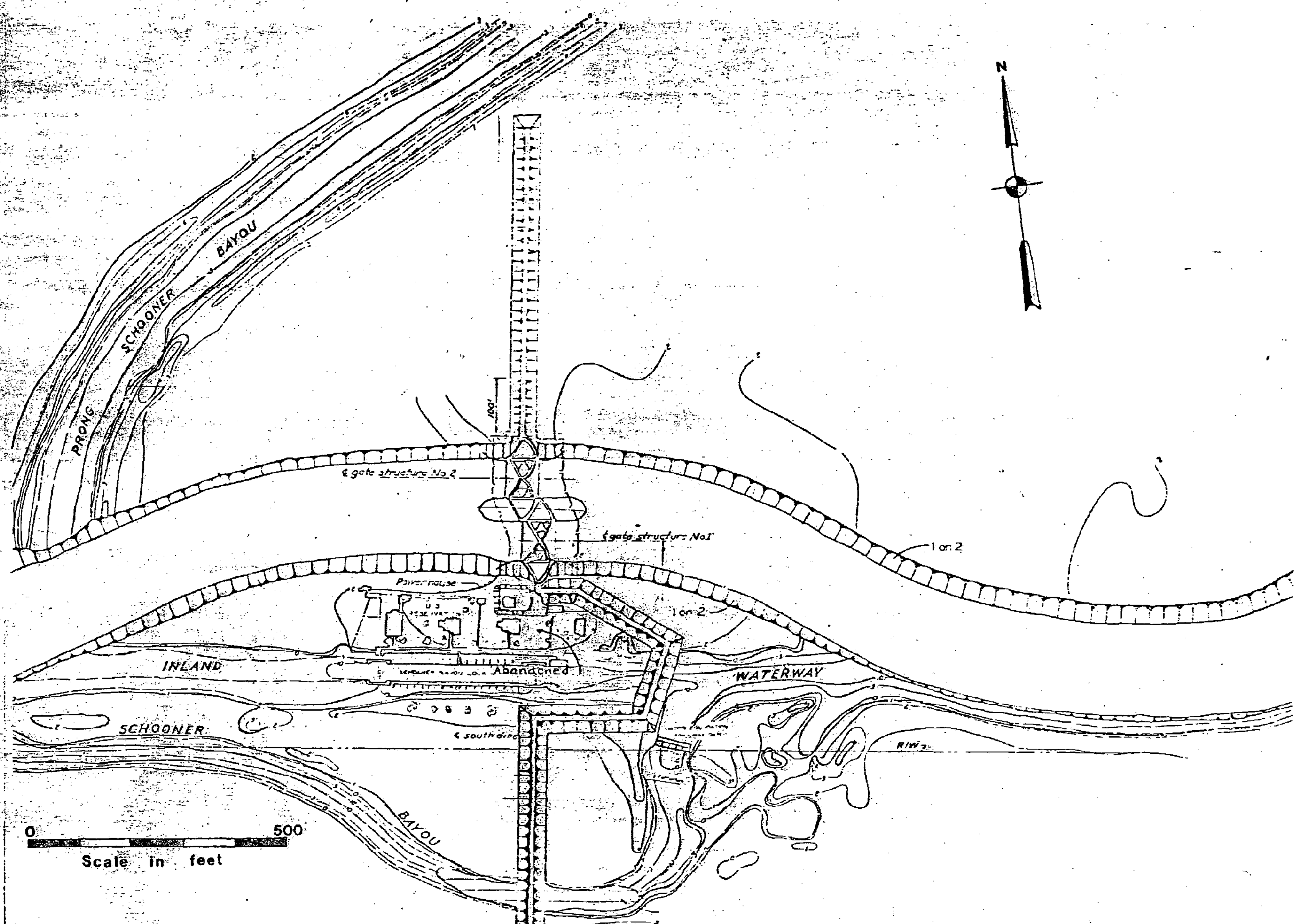
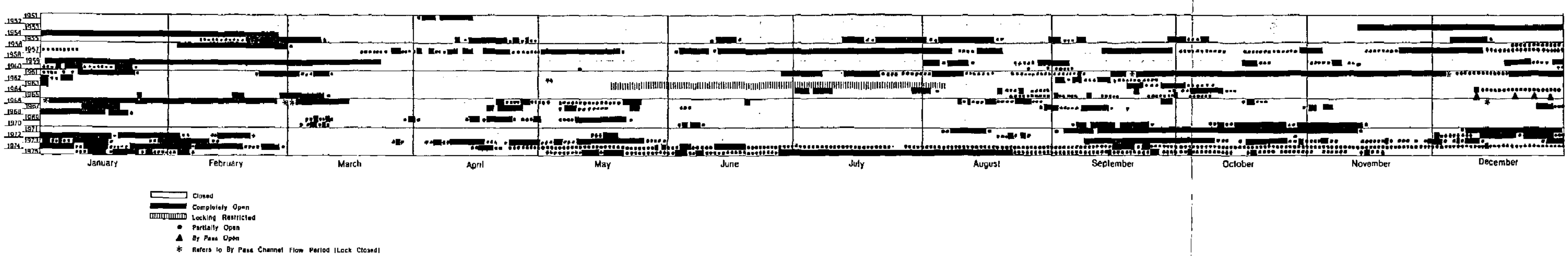


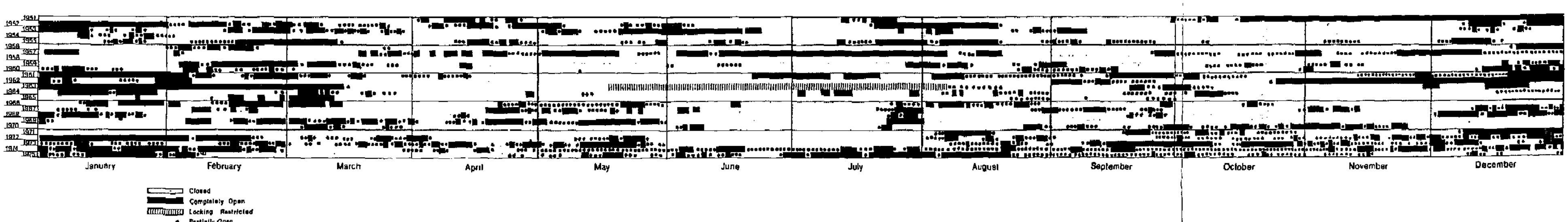
Fig. 20. Diagram of Schooner Bayou Control Structure showing location changes.

Fig. 21. Schooner Bayou and Vermilion Lock Control Structure operational records.

Vermilion Lock



Schooner Bayou Lock



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